Total Productive Maintenance (TPM) Concepts and Literature Review

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1. Abstract

"The ultimate goal of TPM is to implement 'perfect manufacturing'". (Shirose 1992 p. 1) Originally introduced as a set of practices and methodologies focused on manufacturing equipment performance improvement, TPM has matured into a comprehensive equipment-centric effort to optimize manufacturing productivity.[1] "Total Productive Maintenance is based on teamwork and provides a method for the achievement of world class levels of overall *equipment* effectiveness through people and not through technology or systems alone." [Wilmott, 1994 #783 p. 1] This paper examines the basic concepts of TPM and reviews the significant literature related to design, implementation, and maintenance of TPM programs in manufacturing operations. Investigation includes the organizational structures, human interactions, analytical tools, and success criteria associated with the implementation of Total Productive Manufacturing programs.

2. Table of Contents

[1] The commonly used term Total Productive Manufacturing reflects the comprehensive nature of current TPM implementation practices. Total Productive Management is also a term found in the literature to describe TPM practices. The terms 'Total Productive Maintenance', 'Total Productive Management', and 'Total Productive Manufacturing' will be used interchangeably throughout this paper.

3. Definition of TPM

The TPM literature offers a number of definitions for Total Productive Maintenance.

- "TPM is the general movement on the part of businesses to try to do more with less." (Lawrence 1999 p. 63)

- TPM is "an integrated life-cycle approach to factory maintenance and support". (Blanchard 1997 p. 72)

- TPM is a program that "addresses equipment maintenance through a comprehensive productive-maintenance delivery system covering the entire life of the equipment and involving all employees from production and maintenance personnel to top management". (McKone, Schroeder et al. 1999 p. 123)

- TPM is "a way of working together to improve equipment effectiveness". (Society_of_Manufacturing_Engineers 1995 p. vii)

- "TPM is a methodology and philosophy of strategic equipment management focused on the goal of building product quality by maximizing equipment effectiveness. It embraces the concept of continuous improvement and total participation by all employees and by all departments." (Society_of_Manufacturing_Engineers 1995 p. ix)

- "TPM is a production-driven improvement methodology that is designed to optimize equipment reliability and ensure efficient management of plant assets." (Robinson and Ginder 1995 p. 5)

- "TPM is a method for bringing about change. It is a set of structured activities that can lead to improved management of plant assets when properly performed by individuals and teams." (Robinson and Ginder

1995 p. 2)

- TPM is intended to "bring both functions (production and maintenance) together by a combination of good working practices, team working, and continuous improvement." (Cooke 2000 p. 1003)

- TPM is "all of the strategies needed to sustain a healthy maintenance log." (Steinbacher and Steinbacher 1993)

TPM literature indicates that two main approaches to defining TPM exist, the Western Approach and the Japanese Approach (Bamber, Sharp et al. 1999), with significant commonality within the two. Bamber (Bamber, Sharp et al. 1999) in particular describes the Japanese school of thought represented by Nakajima (Nakajima 1984; Nakajima 1989), Tajiri and Gotoh (Tajiri and Gotoh 1992) and Shirose (Shirose 1996) and the Western approach represented by Willmott (Willmott 1994), Wireman (Wireman 1991) and Hartmann (Hartmann 1992). The Japanese Institute of Plant Maintenance (JIPM) promotes the Japanese approach. Siiechi Nakajima is a vice chairman of JIPM and is considered to be the father of TPM. Nakajima's Japanese definition of TPM is characterized by 5 key elements. (Nakajima 1984)

1. TPM aims to maximize equipment effectiveness.
2. TPM establishes a thorough system of Preventive Maintenance (PM) for the equipment's entire life span.
3. TPM is cross-functional, implemented by various departments (engineering, operators, maintenance, managers).
4. TPM involves every single employee.
5. TPM is based on the promotion of Preventive Maintenance through the *motivation* of management and autonomous Small Group Activity (SGA).

Shirose offers a very similar definition for TPM. (Shirose 1996)

1. TPM strives for maximum equipment effectiveness.
2. TPM establishes a total system of Preventive Maintenance for the entire life of the equipment.
3. TPM includes participation by all sectors of the organization that plan, use, and maintain equipment.
4. TPM participation is from top management to the frontline staff.
5. Execution of TPM is based on Small Group Activity.

The Western approach is closely tied to the Japanese approach. Willmott, for instance, acknowledges the Nakajima definition (Japanese Approach) but offers his own definition that is based on teamwork but does not necessarily require total employee participation. He places the emphasis on the use of teams to achieve specific operational goals. "The philosophy at the heart of the TPM process is that all the assets on which production depends are kept always in optimum condition and available for maximum output." (Willmott 1994 p. 2) Hartmann presents a similar definition to Willmott and says, "Total Productive Maintenance permanently improves the overall effectiveness of equipment with the active involvement of operators." (Hartmann 1992 p. 15)

The differences in the Japanese and Western approach to defining TPM are subtle, with commonality highlighted more than significant variation. The Japanese approach emphasizes the role of teamwork, small group activities and the participation of <u>all</u> employees in the TPM process to accomplish equipment improvement objectives. The Western approach focuses on the equipment while understanding that operator involvement and participation in the TPM effort is required. While very similar, the Japanese approach seems to be more people and process focused while the Western definition approaches first from equipment improvement objectives, “which moves the emphasis away from both maintenance and teamwork and towards equipment management and utilization with operator participation.” (Bamber, Sharp et al. 1999 p. 165) V. A. Ames, former TPM Program Manager for SEMATECH, offers an interesting observation related to differences in the Japanese and Western approaches to TPM. “After observing JIPM consultants in Japan and the U.S., as well as attending a TPM Prize audit, I believe that the Japanese are just as focused directly on the results as the Western approach is.” (Ames 2003) He suggests that although there is very little real difference in the approaches, The Western definition emphasizes on results as a marketing, or selling, tool to gain the interest of Western managers.

In 1989, the Japanese Institute of Plant Maintenance (JIPM) acknowledged the emerging trend to widen the scope of TPM activity from a singular focus on equipment to a broader application towards company-wide productivity. JIPM currently defines TPM as follows.

“TPM aims at:

1. Establishing a corporate culture that will maximize production system effectiveness.
2. Organizing a practical shop-floor system to prevent losses before they occur throughout the entire production system life cycle, with a view to achieving zero accidents, zero defects and zero breakdowns.
3. Involving all the functions of an organization including production, development, sales and management.
4. Achieving zero losses through the activities of ‘overlapping small groups’.” (Japan_Institute_of_Plant_Maintenance 1996)

I do not find sufficient conflict between the Japanese and Western definitions of TPM to warrant further discussion of two models of TPM implementation. As will be discussed later in this paper, some degree of process adaptation and customization will always be required to implement TPM (or any other continuous program for that matter) for each implementer's site and operating environment. The following definition will be used to describe Total Productive Manufacturing (Maintenance) through the remainder of this paper. ***Total Productive Manufacturing is a structured equipment-centric continuous improvement process that strives to optimize production effectiveness by identifying and eliminating equipment and production efficiency losses throughout the production system life cycle through active team-based participation of employees across all levels of the operational hierarchy.***

4. Benefits of TPM Implementation

The literature documents dramatic tangible operational improvements resulting from successful TPM implementation. "Companies practicing TPM invariably achieve startling results, particularly in reducing equipment breakdowns, minimizing idling and minor stops (indispensable in unmanned plants), lessening quality defects and claims, boosting productivity, trimming labor and costs, shrinking inventory, cutting accidents, and promoting employee involvement (as shown by submission of improvement suggestions)." (Suzuki 1994 p. 3) He cites, for example, PQCDSM (Productivity, Quality, Cost, Delivery, Safety, Morale) improvements for early TPM implementers in Japan.

- P – Productivity.
  Net productivity up by 1.5 to 2.0 times.

Number of equipment breakdowns reduced by 1/10 to 1/250 of baseline.
Overall plant effectiveness 1.5 to 2.0 times greater.

- Q – Quality.
  Process defect rate reduced by 90%.
  Customer returns/claims reduced by 75%.

- C – Cost: Production costs reduced by 30%.

- D – Delivery: Finished goods and Work in Progress (WIP) reduced by half.

- S – Safety.
  Elimination of shutdown accidents.
  Elimination of pollution incidents.

- M – Morale: Employee improvement suggestions up by 5 to 10 times.

Tajiri and Gotoh observe that, "The actual targets of TPM are fixed more concretely in terms of PQCDSM." (Tajiri and Gotoh 1992 p. 72) Fairchild Semiconductor-Penang Malaysia utilizes TPM as an umbrella program to drive strategic PQCDSM goals (20% OEE improvement on critical production equipment, $14 mil cost savings over five years, for example). (Tan, Hoh et al. 2003) Gardner provides an overview of TPM success at National Semiconductor that is typical of the benefits gained by many companies. "Hundreds of thousands of dollars are being saved each month in terms of reducing lost revenue or in terms of cost avoidance. More efficient equipment and processes means fewer new pieces of equipment need to be purchased to meet demand. Early detection of problems means less resources spent on major breakdowns and scrap. Clean, safe factories are more enjoyable to work in and impress external auditors and customers. Total workforce engagement using TPM methods is a very valuable way to reduce loss and improve profit.” (Gardner 2000 p. 4)

Japanese firms that won the JIPM PM prize between 1984 and 1986 demonstrated similar improvements. (Patterson and Fredendall 1995)

- Equipment failures reduced from 1,000 per month to 20 per month.
- Quality defects reduced from 1.0% to 0.1%.
- Warranty claims reduced by 25%.
- Maintenance costs reduced by 30%.
- WIP decreased by 50%.
- Productivity improved by 50%.

Hartmann also finds tangible results for TPM initiatives in the Non-Japanese plants. (Hartmann 1992)

- Maintenance service calls reduced by 29%.
- Plant output increased by 40%.
- Speed of manufacturing (cycle time) increased by 10%.
- Defects reduced by 90%.
- Productivity increased by 50%.
- Maintenance costs reduced by 30%.
- Return on Investment improved by 262% to 500%.

Specific results for companies are frequently cited, as noted in the following examples.

- **Asten, Inc.**
  ”While Asten instituted TPM in conjunction with other programs such as

TQM…the operating managers give TPM much of the credit". (Patterson, Fredendall et al. 1996 p. 35) Operational performance improvements are noted below.

Performance Metric	1989 Results	1995 Results
Production Cycle Time (order entry to shipping)	67.8 days	<10 days
"Meets all Targets" Operational achievement of manufacturing goals	78.0%	94.8%
Productivity	1.73 lbs per man-hour	1.91 lbs per man-hour
Equipment breakdowns	158 per month	95 per month
Maintenance downtime hours	4,043 man-hours per month	2,050 man-hours per month
Manufacturing reject rate		20% decrease since 1989
WIP level		15% decrease since 1989
Sales		61.6% increase since 1989

- **Texas Instruments – Philippines** (Mika 1999)

  The Texas Instruments – Philippines assembly plant was the first American semiconductor operation to win the JIPM TPM Prize. Highlights of their TPM-based improvement include the following.

  - Increased annual revenue from $350M to >$1,000M between 1992 and 1998 without adding people or expanding production floor space.
  - Increased productivity 25% annually to stay ahead of the annual Philippines inflation rate of 15% to 18%.
  - Reduced scrap by 90%.
  - Reduced cycle time by 50%.
  - Reduced quality defects from 4,000 ppm to 50 ppm.
  - Decreased production costs by 50%.

  According to Plant Manager, Don Mika, "the first benefit of TPM implementation was that people could exercise their minds at work and feel pride in their efforts. Over time we could feel a change in attitude throughout the company". (Mika 1999 p. 7)

- **Eastman Chemical**

  "Eastman Chemical Company has effectively used Total Productive Maintenance (TPM) to reduce maintenance costs by $16 million per year and improve equipment uptime." (McCloud 1998 p. 1)

  - Reduced requests for equipment energize/de-energize by 20,000 calls per year resulting in labor savings of $1.3 million.

- Increased equipment uptime by 36,000 hours per year.
- Reduced maintenance response time from 54 minutes to 18 minutes as a result of improved equipment availability.
- Zero maintenance accidents reported during TPM implementation.
- Multi-skill training for operators resulted in $5 million labor saving.

Intangible benefits of TPM implementation are also cited frequently in the literature. Suzuki, for example, identifies intangible results of TPM implementation that include self-management of shop-floor workers, improved confidence of production workers, clean up of production and administrative areas, and improved company image for customers. (Suzuki 1994) At Fairchild Semiconductor Tan notes that TPM is key to getting people together to own processes and performance of the machine and builds teamwork on the shop floor, leading to a standard and disciplined work culture, and improved engineering discipline. (Tan, Hoh et al. 2003) While TPM Program Manager for SEMATECH, Ames observed that the intangible benefits of TPM implementation in semiconductor operations included increased management involvement in day-to-day activities, higher level of shop floor employee involvement (team activities) in improvement activity, and greater employee empowerment. (Ames 2003)

5. History of TPM

The earliest roots of TPM trace back to the concept of Productive Maintenance (PM) that originated in the United States in the late 1940’s and early 1950’s. American Productive Maintenance was characterized by development of scheduled Preventive Maintenance techniques to improve the reliability and longevity of manufacturing production equipment.[2] "What we now refer to as TPM is, in fact, American-style productive maintenance modified and enhanced to fit the Japanese industrial environment." (Nakajima 1984) Twenty Japanese companies formed a PM research group in 1953 and in 1962 sent a research mission to the United States to observe American Productive Maintenance. This effort further led to the creation of the Japanese Institute of Plant Engineers (JIPE), the predecessor of JIPM in 1969. (Ireland and Dale 2001) Figure 1 provides an overview of the early milestones as TPM developed in Japan. (Nakajima 1984)

Era	**1950's**	**1960's**	**1970's**
Emerging Concepts	Preventive Maintenance – Establishing scheduled maintenance functions	Productive Maintenance (PM) – Recognizing the importance of equipment reliability, maintenance and ergonomic efficiency in plant design	Total Productive Maintenance (TPM) – Achieving PM efficiency through a comprehensive system based on respect for individuals and total employee participation
Supporting Theories	▪ Preventive Maintenance (PM) 1951 ▪ Productive Maintenance (PM) 1954 ▪ Maintainability Improvement (MI) 1957	▪ Maintenance Prevention (MP) 1960 ▪ Reliability Engineering 1962 ▪ Maintainability Engineering 1962 ▪ Engineering Economics	▪ Behavioral Science ▪ Management by Innovation and Creation (MIC) ▪ Performance Analysis and Control (PAC) ▪ Systems Engineering ▪ Ecology ▪ Terotechnology ▪ Maintenance Logistics
Significant Historical Events	1951 – Toa Nenryo Kogyo 1st Japanese company to adopt PM 1953 – 20 Japanese companies form a PM	1960 – Japan hosts the first international maintenance convention 1962 – Japan Productivity Association sends an	1970 – the annual International Convention on Equipment Maintenance held in Japan

2 Preventive Maintenance is characterized by routine maintenance activity such as inspection, adjustment, or component replacement performed on a scheduled basis before an equipment failure occurs. Reliability Engineering methodology plays a large role in analyzing equipment failure modes and frequency to determine optimal PM scheduling. This paper will not include an in-depth discussion of Reliability Engineering practices and methods.

Era	1950's	1960's	1970's
	research group which later became JIPM 1958 – American George Smith visits Japan to promote PM	envoy to the U.S. to study equipment engineering 1963 – Japan attends the International Convention on Equipment Maintenance in London 1964 – the first PM prize is awarded to Nippondenso in Japan 1969 – Japan Institute of Plant Engineers (JIPE) established, later to become Japan Institute of Plant Maintenance (JIPM)	1973 – the United Nations Industrial Development Organization sponsors a Maintenance Repair Symposium in Japan

Figure 1 - TPM Development in Japan

The first use of the term Total Productive Maintenance was in the Japanese automotive component manufacturer Nippondenso in 1961, where the company improvement theme was 'Productive Maintenance with Total Employee Participation'. (Robinson and Ginder 1995) Nippondenso would later become the first company to win the JIPM PM prize for TPM implementation. Early TPM implementation in Japan was primarily within the automotive industry, particularly within Toyota and their associated component suppliers. (Robinson and Ginder 1995) Nissan and Mazda soon followed Toyota in implementing TPM in, at least, some of their manufacturing sites. Seiichi Nakajima was one of the earliest proponents of this effort and soon became known as the Father of TPM for his work with JIPE and JIPM. The earliest Japanese TPM implementations met with limited success and only a small number of companies initiated the effort. (Tajiri and Gotoh 1992) In the early 1970's, Japan faced a worsening economic climate and adoption of TPM began to accelerate as a means to improve manufacturing productivity. (Ireland and Dale 2001) Structured and phased implementation processes such as those developed by

Nakajima (Nakajima 1984; Nakajima 1989) provided standardized and repeatable methodology for TPM.

TPM spread to America and the Western world in the 1980's and 1990's as companies jumped on the quality bandwagon with programs such as Total Quality Management (TQM). (Ireland and Dale 2001) Early Western TPM adopters included Dupont, Exxon, Kodak, Alcoa, AT&T, Ford, Hewlett-Packard, and Proctor and Gamble. (Suzuki 1994) A number of authors document the successful growth of TPM in Western manufacturing enterprises. (Nakajima 1988; Nakajima 1989; Hartmann 1992; Sekine and Arai 1992; Willmott 1994) Since the mid-1980's case studies extolling the benefits of TPM implementation proliferated through the efforts of Productivity, Inc. in their newsletter The TPM Report (McCloud 1998; Productivity 1998; Mika 1999) and their annual TPM Conference and Exposition [Adams, 2000 #229; Crow, 1996 #252; Custer, 1999 #238; Gardner, 2000 #231; Howren, 1999 #244; Leflar, 1999 #237]. Asten, Inc. recognized the importance of equipment performance in achieving overall company production goals and introduced TPM in 1989 as part of their effort to win the Malcolm Baldridge Award. "At many companies where maintenance is viewed as an operational expense to be minimized and not as an investment in increased process reliability, the maintenance practices decrease their competitiveness by reducing throughput, increasing inventory, and leading to poor due-date performance." (Patterson, Fredendall et al. 1996 p. 32) The U.S. semiconductor industry recognized the high value potential of TPM implementation and organized an industry-wide effort to establish share TPM learning and establish standardized TPM implementation and management practices and methodologies. SEMATECH, a consortium of major U.S. semiconductor manufacturers[3] chartered a TPM Steering Committee in the mid 1990's to develop a roadmap for TPM implementation (SEMATECH-International 1998) and an auditing process for TPM programs (SEMATECH-International 1996). The SEMATECH TPM Steering Committee also hosted a series of workshops in which TPM practitioners shared learning's related to the implementation and execution of their TPM programs. (Bahrani 1995; Ames 1996; Pomorski 1996; Studebaker 1996)

By the late 1990's, TPM was well entrenched as a continuous improvement methodology across a wide range of industries. To illustrate, look at the mix of enterprises that have been awarded the TPM Prize by JIPM, Figure 2, as of 1996. (Shirose 1996)

Manufacturing Type	**Sector**	**Number of TPM Prize Winners**
Fabrication and Assembly	Auto Parts	204
	Semiconductor and Electronic Devices	56
	Electronic Machinery and Parts	33
	General Machinery and Parts	32
	Automotive and Vehicles	26
	Precision Machinery and Parts	15
Process	Chemicals	44
	Plastics	41
	Cement and Ceramics	40

[3] International SEMATECH, located in Austin, TX, is a consortium of leading semiconductor manufacturers that engage in cooperative, pre-competitive efforts to improve semiconductor manufacturing technology. Originally formed in 1987 as SEMATECH in partnership with the U.S. government to help restore American leadership in semiconductor manufacturing, the consortium expanded its scope of operations to include non-U.S. membership in 2000 when it evolved into International SEMATECH. International_SEMATECH (2003). International SEMATECH web page, International SEMATECH.

	Printing	31
	Foodstuffs	29
	Rubber	24
	Ferrous Metal	19
	Paper and Pulp	13
	Steel and Iron	13
	Petroleum and Coal	8
	Textiles	7
	Electric and Gas	4

Figure 2 - TPM Awards by Industry Type

6. TPM Basic Concepts And Structures

As noted earlier in the is paper, the working definition for TPM is; *Total Productive Manufacturing is a structured equipment-centric continuous improvement process that strives to optimize production effectiveness by identifying and eliminating equipment and production efficiency losses throughout the production system life cycle through active team-based participation of employees across all levels of the operational hierarchy.* The key elements of this definition will be investigated further.

- Structured Continuous Improvement Process.
- Optimized Equipment (Production) Effectiveness.
- Team-based Improvement Activity.
- Participation of employees across all levels of the operational hierarchy.

6.1 The TPM Structured Continuous Improvement Process

One of the most significant elements of TPM the structured TPM implementation process is that it is a consistent and repeatable methodology for continuous improvement. "For world-class competitors, minimal performance requirements include repetitive and predictable year-over-year actual per-unit cost reductions, ever-reducing variation, improved product quality, and extraordinary customer service. Winning requires an institutionalized management proof process that is sustainable despite changes in leadership, strategy, and business conditions – a corporate culture dedicated to manufacturing excellence." [Elliot, 2001 #879 p. 7] While touring TPM Prize winning plants in Japan I observed, "All of the plants visited followed a strict JIPM TPM implementation process. The use of the 8 pillars of TPM to focus attention on opportunities was evident in all of the visits." (Pomorski 1997 p. 3) This particular tour was biased towards the JIPM approach, since they were the tour's hosting organization, however, TPM literature clearly emphasizes the significance of a well-defined and structured approach to TPM implementation. V.A. Ames, former manager of SEMATECH's TPM program, concurs that "following the process and fully completing all the requirements of a step or process before going on to the next one" is a key to a successful TPM effort. (Ames 2003 p. 3) A driving consideration for this structured approach is the fact that successful TPM implementation takes from three to five years, (Nakajima 1984; Nakajima 1988; Robinson and Ginder 1995; Society_of_Manufacturing_Engineers 1995; Ames 2003) with an average of three and a half years from introduction to achievement of TPM Prize winning results. (Wang and Lee 2001) "For the most part, participants talked about TPM as a long-term process, not a quick fix for today's problems." (Horner 1996 p. 9) Interestingly, of nine U.S. semiconductor companies interviewed on their

TPM implementations, the two companies that most closely followed the JIPM structured process "gave the highest ranking to the question asking them to rate the effectiveness of TPM implementation as compared to their expectations." (Horner 1996 p. 3)

Although "there is no single right method for implementation of a T.P.M. program" (Wireman 1991 p. 17) and there has been "a complexity and divergence of TPM programs adopted throughout industry" (Bamber, Sharp et al. 1999 p. 165) it is clear that a structured implementation process is an identified success factor and a key element of TPM programs.

6.1.1 The Pillars of TPM

The principle activities of TPM are organized as 'pillars'. Depending on the author, the naming and number of the pillars may differ slightly, however, the generally accepted model is based on Nakajima's eight pillars[4] (Nakajima 1984; Nakajima 1988), as presented in Figure 3.

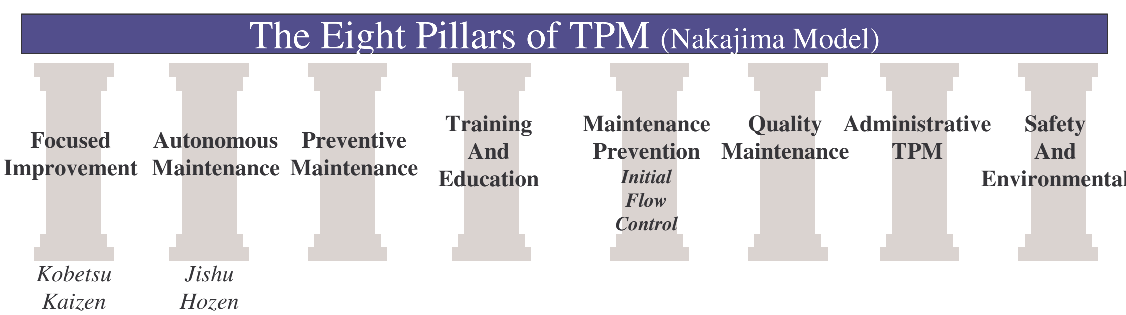

Figure 3 - TPM Pillars (Nakajima Model)

[4] Note that Japanese terms for some if the pillars are included. See Appendix I for a review of Japanese terms that are commonly used in TPM programs.

Some Western TPM practitioners have simplified the Nakajima model by eliminating pillars. Figure 4 for example, presents a five-pillar model that maps to five of Nakajima's pillars. (Yeomans and Millington 1997)

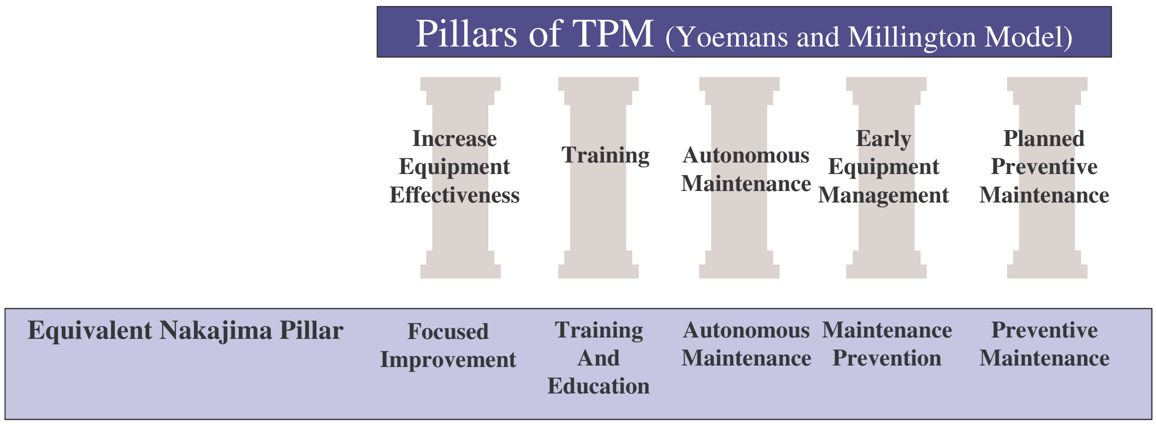

Figure 4 - TPM Pillars (Yoemans and Millington Model)

A similar simplified Western pillar model is presented in Figure 5. (Steinbacher and Steinbacher 1993) In this model, Training and Education are an integral element of the other pillars rather than a stand-alone pillar as in the Nakajima Model.

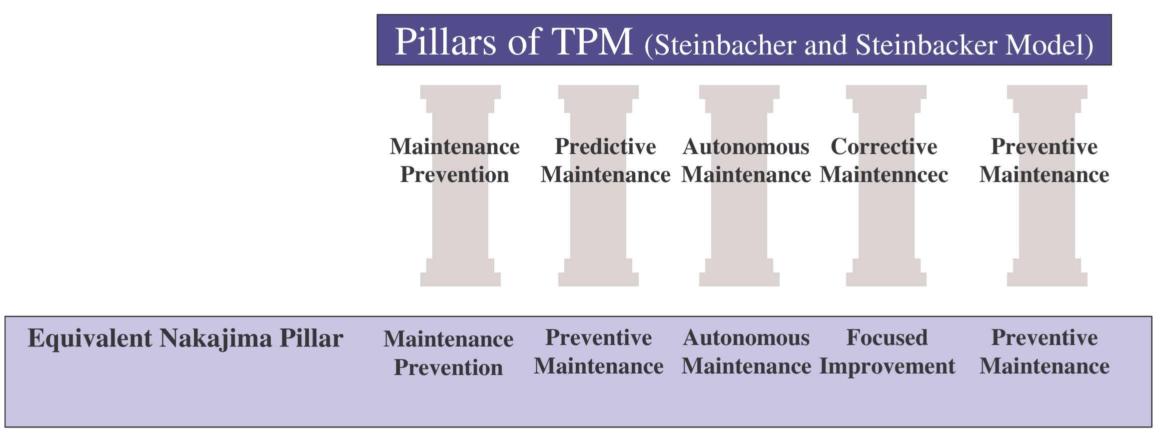

Figure 5 - TPM Pillars (Steinbacher and Steinbacher Model)

And in Figure 6. (Society_of_Manufacturing_Engineers 1995)

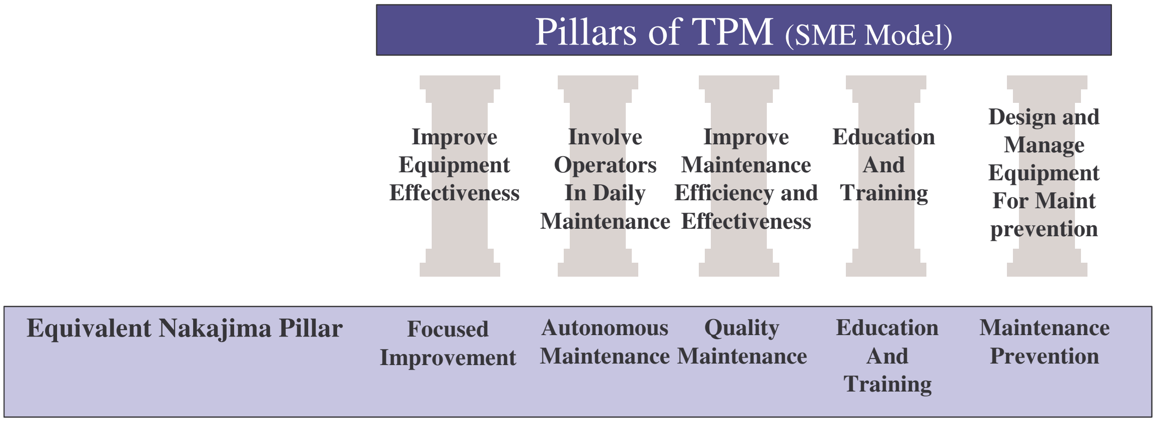

Figure 6 - TPM Pillars (SME Model)

The key concepts of each pillar are discussed in further detail.

6.1.1.1 Focused Improvement Pillar (Kobetsu Kaizen)

"Focused improvement includes all activities that maximize the overall effectiveness of equipment, processes, and plants through uncompromising elimination of losses[5] and improvement of performance." (Suzuki 1994 p. 1992) The objective of Focused Improvement is for equipment to perform as well every day as it does on its best day. "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 to 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." (Leflar 2001 p. 15) The driving concept behind

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[5] Losses may be either a function loss (inability of an equipment to execute a required function) or a function reduction (reduced capability without complete loss of a required function). Tajiri, M. and F. Gotoh (1992). TPM Implementation - A Japanese Approach. New York, McGraw Hill.

Focused Improvement is *Zero Losses*. "Maximizing equipment effectiveness requires the complete elimination of failures, defects, and other negative phenomena – in other words, the wastes and losses incurred in equipment operation." (Nakajima 1988 p. xix)

Leflar identifies a critical TPM paradigm shift that is the core belief of Focused Improvement.

- <u>Old Paradigm</u> – New equipment is the best it will ever be.
- <u>New Paradigm</u> – New equipment is the worst 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 continuously 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." (Leflar 2001 p. 18) Thomas notes that Focused Improvement methodologies have led to short-term and long-term improvements in equipment capacity, equipment availability, and production cycle time. "Focused Improvement has been, and still is, the primary methodology for productivity improvement in the [Advanced Micro Devices – AMD] Fab 25." (Thomas 2003)

Overall Equipment Effectiveness (OEE)[6] is the key metric of Focused Improvement. [7] Focused Improvement is characterized by a drive for Zero Losses,

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[6] The basic concept of OEE and Equipment Losses will be reviewed in this paper. A more detailed discussion of OEE and other productivity metrics will be included in a subsequent paper currently in development.
[7] Additional discussion of OEE calculation is included in section 6.2 of this paper.

meaning a continuous improvement effort to eliminate any effectiveness loss[8]. Equipment losses may be either chronic (the recurring gap between the equipment's actual effectiveness and its optimal value) or sporadic (the sudden or unusual variation or increase in efficiency loss beyond the typical and expected range), as illustrated in Figure 7. (Tajiri and Gotoh 1992)

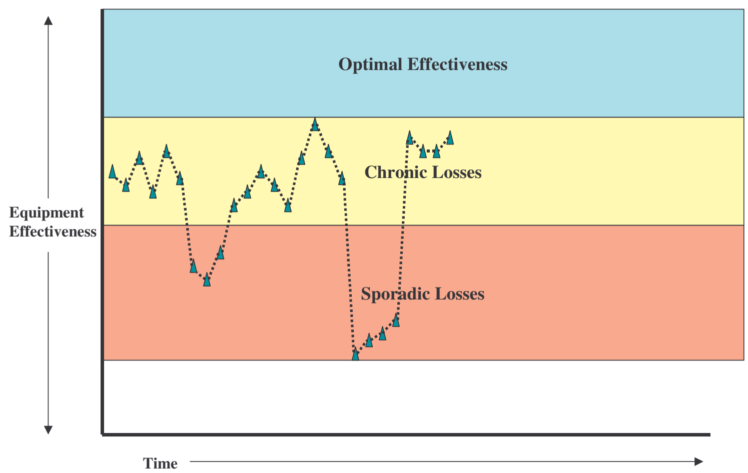

Figure 7 - Chronic versus Sporadic Losses

Figure 8 - TPM Pyramid of Chronic Conditions shows the progression of chronic conditions to equipment failures.

[8] The definition of effectiveness losses is not consistent among the Japanese authors. Nakajima originally defined six 'Big Equipment Losses' (Equipment Failure, Setup and Adjustment, Idling and Minor Stoppages, Reduced Speed, Defects in Process, and Reduced Yield). Nakajima, S. (1984). Introduction to TPM: Total Productive Maintenance. Cambridge, MA, Productivity Press. Suzuki suggests 'Eight Major Plant Losses' (Shutdown, Production Adjustment, Equipment Failure, Process Failure, Normal Production Loss, Abnormal Production Loss, Quality Defects, and Reprocessing). Suzuki, T., Ed. (1994). TPM in Process Industries. Portland, OR, Productivity Press. Shirose expanded the number of losses to sixteen to include human effectiveness losses such as Management Losses, Motion Losses, Arrangement Losses, Loss due to Lack of Automated Systems, and Monitoring and Adjustment Losses. Shirose, K. (1992). TPM for Operators. Portland, OR, Productivity Press.

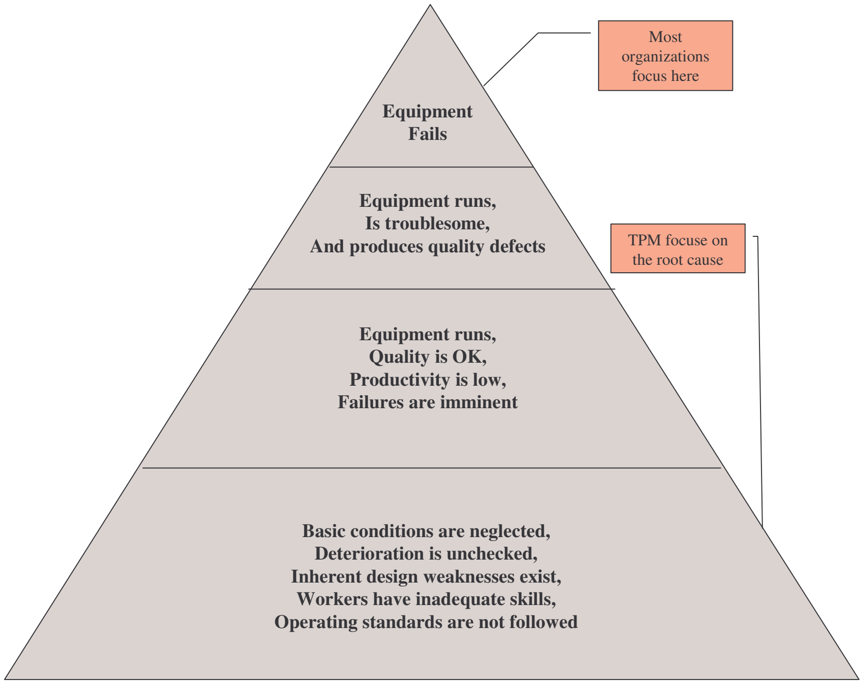

Figure 8 - TPM Pyramid of Chronic Conditions

Causal factor relationships for equipment effectiveness loss are displayed in Figure 9.

The loss causal factors may be,

- Single – a single causal factor for the effectiveness loss.
- Multiple – two or more causal factors combined result in the effectiveness loss.
- Complex – the interaction between two or more causal factors results in the effectiveness loss.

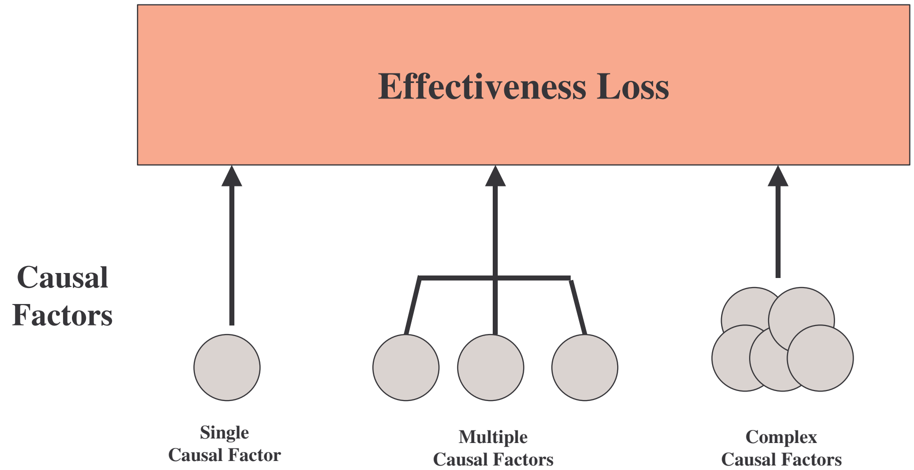

Figure 9 - Effectiveness Loss Causal Factor Relationships

Focused Improvement includes three basic improvement activities. First, the equipment is restored to its optimal condition. Then equipment productivity loss modes (causal factors) are determined and eliminated.[9] The learning that takes place during restoration and loss elimination then provide the TPM program a definition of optimal equipment condition that will be maintained (and improved) through the life of the equipment

Equipment restoration is a critical first step in Focused Improvement, as illustrated in Figure 8. "Maintaining basic equipment conditions is a maintenance practice that is ignored in most companies today. When the maintenance group gets occupied with capacity loss breakdowns and trying to keep the equipment running properly, basic tasks like cleaning, lubricating, adjusting, and tightening are neglected." (Wireman 1991 p. 23) Nakajima claims that equipment failure is eliminated by exposing and eliminating hidden defects (fuguai). (Nakajima 1988)

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[9] See Suehiro, K. (1987). Eliminating Minor Stoppages on Automated Lines. Portland, OR, Productivity Press. for an excellent discussion on identifying and eliminating minor stoppage productivity losses on automated production equipment.

Tajiri and Gotoh concur with Nakajima and state that the critical steps to eliminate equipment restoration is to expose the hidden defects, deliberately interrupt equipment operation prior to breakdown, and to resolve minor defects promptly. (Tajiri and Gotoh 1992) Shirose notes, "the first aim of attaching importance to minor defects is to 'cut off synergic effects do to the accumulation of minor defects'." (Shirose 1996 p. 93) Even though a single minor defect may have a negligible impact on equipment performance, multiple minor defects may stimulate another factor, combine with another factor, or may cause chain reactions with other factors. (Shirose 1996) Suehiro considers the elimination of minor defects to be one of the highest priorities of continuous improvement. "It is important to realize that even in large equipment units or large-scale production lines, overall improvement comes as an accumulation of improvements designed to eliminate slight defects. So instead of ignoring them, factories should make slight defects their primary focus." (Suehiro 1987 p. xv)

Minor or hidden defects result from a number of causal factors (Tajiri and Gotoh 1992) such as:

- Physical Reasons.
    - Contamination (dust, dirt, chemical leaks, etc.).
    - Not visible to the operator.
    - Excessive safety covers.
    - Equipment not designed for ease of inspection.

- Operator Reasons.
    - Importance of visible defects not understood.
    - Visible defects not recognized.

According to Jim Leflar (Agilent Technologies)[10], "The power of that step [Focused Improvement] continues to amaze me." (Leflar 2003) During Agilent's equipment restoration effort hundreds of minor defects were discovered on equipment that was previously thought to be in good running order. In many cases, equipment restoration resolved chronic losses where the root cause was never identified. "Minor Defects are the root cause of many equipment failures and must be completely eliminated from all equipment. Eliminating minor defects attacks the *Roseannadanna Syndrome* – 'It's always something!' Machines with minor defects will always find new ways to fail. (Leflar 1999 p. 6) Steinbacher and Steinbacher refer to the unrelenting pursuit of resolving small problems as '*majoring in minors*'. (Steinbacher and Steinbacher 1993)

"Tracking OEE provides a relative monitor of equipment productivity and the impact of improvement efforts. Understanding efficiency losses drives the improvement effort." (DiIorio and Pomorski 2003 p. 41) Typically, productivity losses are determined through analysis of equipment and production performance histories. The impact of productivity losses should be analyzed from two perspectives; 1) the frequency of loss (the number of occurrences during the time period), and 2) the impact of the loss (the number lost hours, lost revenue, cost, etc.). A number of tools are commonly used to analyze productivity losses in the Focused Improvement pillar.

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[10] Jim Leflar uses the term 'Precision Maintenance' to describe his approach to TPM-oriented maintenance activity. For addition information see Leflar, J. (2001). Practical TPM. Portland, OR, Productivity Press. and Leflar, J. (2000). Achieving Precision Maintenance. 11th Total Productive Maintenance Conference and Exposition, Dallas, TX, Productivity, Inc..

- Pareto Charts.
- 5-Why Analysis.
- Fishbone Diagrams.
- P-M Analysis.
- Fault Tree Analysis (FTA).
- Failure Mode and Effects Analysis (FMEA).

"Companies differ in their approaches to systematic improvement, but all incorporate roughly the same basic elements: planning, implementing, and checking results." (Productivity 1998 p. 3) Suzuki reinforces the objective of Focused Improvement to eliminate losses. "Focused Improvement includes all activities that maximize the overall effectiveness of equipment, processes, and plants through the uncompromising elimination of losses and improvement of performance." (Suzuki 1994 p. 45) Similar to Leflar, Suzuki considers the establishment of basic conditions (equipment restoration), compliance with conditions of use, the reversal of deterioration, and elimination of the environmental conditions that accelerate deterioration to be the key elements of the Focused Improvement pillar, as presented in Figure 10. (Suzuki 1994)

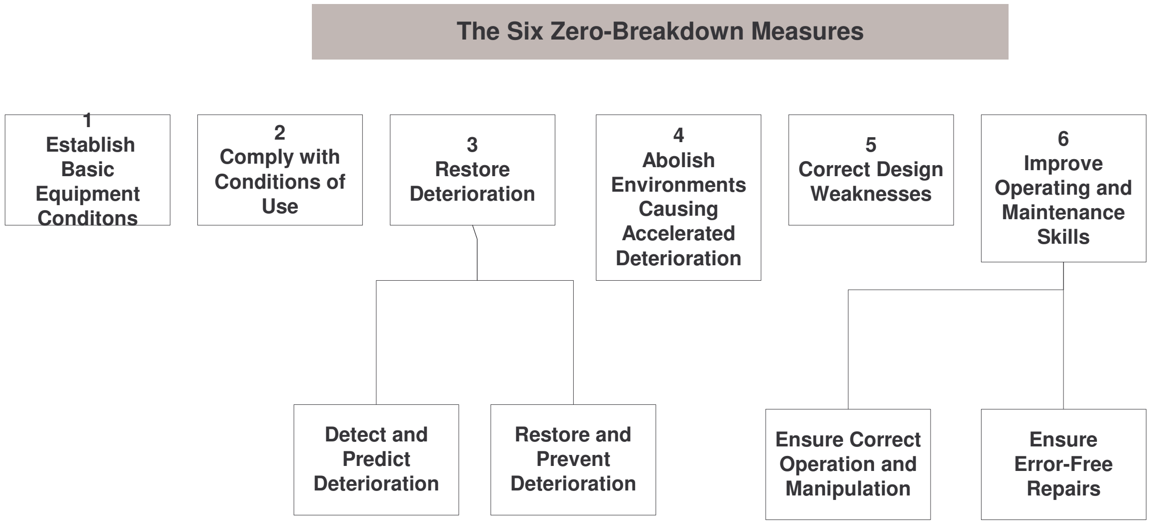

Figure 10 - The Six Zero-Breakdown Measures

It is important to note that Focused Improvement and equipment restoration is not a one-time activity. Usage results in wear and potential deterioration. "Restoring normal equipment wear is a process that continues for the entire life of the equipment." (Wireman 1991 p. 26)

6.1.1.2 Autonomous Maintenance Pillar (Jishu Hozen)

"Autonomous maintenance is the process by which equipment operators accept and share responsibility (with maintenance) for the performance and health of their equipment." (Robinson and Ginder 1995 p. 57) The driving concept of Autonomous Maintenance (AM) is the creation of 'expert equipment operators' for the purpose of 'protecting their own equipment'. (Shirose 1996) "Autonomous maintenance is the cornerstone of TPM activities." (Komatsu 1999 p. 2) The paradigm shift that AM addresses is a transition in the operator perception from 'I run the equipment, Maintenance fixes it', to 'I own the performance of this equipment'. In this Autonomous Maintenance environment, "The greatest requirements for operators are, first, to have the ability to 'detect abnormalities' with regard to quality or equipment, based on a feeling that 'there is something wrong'." (Shirose 1996 p. 208) Autonomous Maintenance is closely linked with Focused Improvement in that both TPM pillars support equipment restoration and sustaining basic equipment conditions.

"Through autonomous activities – in which the operator is involved in daily inspection and cleaning of his or her equipment – companies will discover the most important asset in achieving continuous improvement – its people." (Society_of_Manufacturing_Engineers 1995 p. 3) Autonomous Maintenance has two aims, 1) to foster the development and knowledge of the equipment operators, and 2) to establish an orderly shop floor, where the operator may detect departure from optimal conditions easily. (Tajiri and Gotoh 1992) Autonomous Maintenance offers a significant departure from Taylor-ism (Taylor 1911; Taylor 1911) where operators are required to repeat simple structured work tasks with little understanding and knowledge about the equipment they run or the products they manufacture. "Autonomous Maintenance involves the participation of each and every operator, each maintaining his own equipment and conducting activities to keep it in the proper condition and running correctly. It is the most basic of the eight pillars of TPM. If autonomous maintenance activities are insufficient, the expected results will not materialize even if the other pillars of TPM are upheld." (Komatsu 1999 p. 3)

Autonomous Maintenance empowers (and requires) equipment operators to become knowledgeable managers of their production activities, able to:

- Detect signs of productivity losses.
- Discover indications of abnormalities (fuguai).
- Act on those discoveries.

JIPM describes the critical operator Autonomous Maintenance skills to be (Japan_Institute_of_Plant_Maintenance 1997):

- Ability to **discover** abnormalities.
- Ability to **correct** abnormalities and restore equipment functioning.
- Ability to **set** optimal equipment conditions.
- Ability to **maintain** optimal conditions.

To that end, JIPM and Productivity, Inc. defines the operator skill levels required to support Autonomous Maintenance (Japan_Institute_of_Plant_Maintenance 1997; Productivity 2000). (Figure 11)

Level 1	Recognize deterioration and improve equipment to prevent it. ▪ Watch for and discover abnormalities in equipment operation and components. ▪ Understand the importance of proper lubrication and lubrication methods. ▪ Understand the importance of cleaning (inspection) and proper cleaning methods. ▪ Understand the importance of contamination and the ability to make localized improvements.
Level 2	Understand equipment structure and functions. ▪ Understand what to look for when checking mechanisms for normal operation.

	▪ Clean and inspect to maintain equipment performance. ▪ Understand criteria for judging abnormalities. ▪ Understand the relationship between specific causes and specific abnormalities. ▪ Confidently judge when equipment needs to be shut off. ▪ Some ability to perform breakdown diagnosis.
Level 3	Understand causes of equipment-induced quality defects. ▪ Physically analyze problem-related phenomena. ▪ Understand the relationship between characteristics of quality and the equipment. ▪ Understand tolerance ranges for static and dynamic precision and how to measure such precision. ▪ Understand causal factors behind defects.
Level 4	Perform routine repair on equipment. ▪ Be able to replace parts. ▪ Understand life expectancy of parts. ▪ Be able to deduce causes of breakdown.

Figure 11 - Operator Autonomous Maintenance Skill Levels

The specific goals of Autonomous Maintenance include the following. (Suzuki 1994)

- Prevent equipment deterioration through correct operation and daily inspections.
- Bring equipment to its ideal state through restoration and proper management.
- Establish the basic conditions needed to keep equipment well maintained.

Four significant elements of the Autonomous Maintenance effort are discussed in further detail in this section:

1. Initial Clean,
2. 5-S,
3. Manager's Model and Pilot Teams.
4. Visual Controls and One Point Lessons.

6.1.1.2.1 Initial Clean

Cleaning equipment is typically the first phase in Autonomous Maintenance. Known as the Initial Clean within the AM program, this really means inspection of equipment. The philosophy being that in the process of cleaning the operator discovers fuguai. "From the TPM perspective…cleaning is aimed at exposing and eliminating hidden defects." (Tajiri and Gotoh 1992 p. 86) The TPM Initial Clean is part of the early TPM training and is performed by a small team that includes the operator responsible for the area, maintenance personnel who work on the tool, the area production supervisor, and others with a vested interest in performance of the production area[11]. A qualified TPM trainer should act as facilitator for the Initial Clean activity. (Robinson and Ginder 1995) Suzuki suggests seven types of abnormalities that should be the focus of the Initial Clean activity. (Suzuki 1994) (Figure 12)

Type of Abnormality	**Abnormality**	**Examples**
Minor Flaws	Contamination	Dust, dirt, powder, grease, rust, paint
	Damage	Cracking, crushing, deformation, chipping, bending
	Play	Shaking, falling out, tilting, eccentricity, wear, distortion, corrosion
	Slackness	Belts, chains
	Abnormal phenomena	Unusual noise, overheating, vibration, strange smells, discoloration, incorrect pressure or other parameter
	Adhesion	Blocking, hardening, accumulation of debris, peeling, malfunction
Unfulfilled Basic Conditions	Lubrication	Insufficient, dirty, unidentified, unsuitable, leaking
	Lubrication supply	Dirty, damaged, deformed inlets, faulty lubricant pipes
	Oil level gauges	Dirty, damaged, leaking, no indication of correct level

[11] Prior to starting the Initial Clean process, the team should receive training in equipment operation and safety precautions so that the Initial Clean can proceed at no risk to the equipment or the team members.

Type of Abnormality	**Abnormality**	**Examples**
	Tightening	Nuts and bolts – slackness, missing, cross-threaded, too long, crushed, corroded, washer unsuitable, backwards
Inaccessible Places	Cleaning	Machine construction, covers, layout, footholds, access space
	Checking	Covers, construction, layout, instrument position and orientation, operating-range display
	Lubricating	Position of lubricant inlet, construction, height, footholds, lubricant outlet, space
	Operation	Machine layout, position of valves/switches/levers, footholds
	Adjustment	Position of pressure gauges/thermometers/flow meters/etc.
Contamination Sources	Product	Leaks, spills, spurts, scatter, overflow
	Raw materials	Leaks, spills, spurts, scatter, overflow
	Lubricants	Leaking, split, seeping
	Gases	Leaking
	Liquids	Leaking, split, spurting
	Scrap	Flashes, cuttings, packaging materials, scrap/rework product
	Other	Contaminants brought in by people/equipment
Quality Defect Sources	Foreign matter	Inclusion, infiltration, entrainment
	Shock	Dropping, jolting, collision, vibration
	Moisture	Control (too little/too much), infiltration, defective elimination
	Filtration	Abnormalities in filter mechanisms
Unnecessary and Non-urgent items	Machinery	Excessive or unused
	Piping	Pipes, hoses, ducts, valves, etc
	Measurement instruments	Temperature, pressure, vacuum, etc.
	Electrical Equipment	Wiring, switches, plugs, etc.
	Jigs and tooling	General tools, jigs, molds, dies, frames, etc.
	Spare parts	Equipment spares, process spares, etc.
	Repairs in progress	Components and maintenance tooling
Unsafe Places	Floors	Uneven, projections, cracking, peeling, wear
	Steps	Too steep, irregular, pealing, corrosion, missing handrails
	Lights	Dim, out of position, dirty, broken covers
	Rotating machinery	Displaced, broken/missing covers, no emergency stops
	Lifting gear	Hooks, brakes, cranes, hoists
	Other	Special/dangerous substances, danger signs, protective clothing/gear

Figure 12 - Types of Equipment Abnormalities

A TPM jingle associated with Initial Clean summarizes the driving concept.

Clean to Inspect,

Inspect to Detect,

Detect to Correct,

Correct to Perfect!

This concept can be presented graphically, as in Figure 13. (Tajiri and Gotoh 1992)

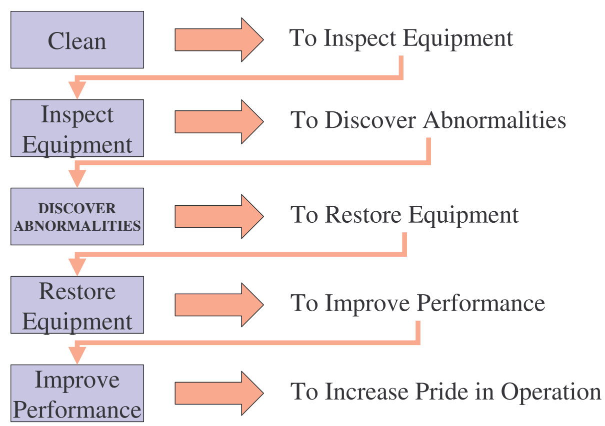

Figure 13 - The Role of CLEAN in Autonomous Maintenance

The purpose of the Initial Clean is threefold. (Robinson and Ginder 1995)

1. Small Work Groups (also known as Small Group Activity- SGA) are able to join together to accomplish a common goal, the cleaning of a particular equipment or area.
2. Promote a better understanding of, and familiarity with, the equipment or process area.
3. Uncover hidden defects that, when corrected, have a positive effect on equipment performance.

6.1.1.2.2 5S

5S is "a systematic method to organize, order, clean, and standardize a workplace – and keep it that way." (Productivity 1999 p. 1-10) 5S is based on a Japanese approach to establishing and maintaining an organized and effective workplace.[12] The elements of 5S include the following. (Willmott 1994)

1. Seiri (Organization).
2. Sieton (Orderliness).
3. Seiso (Cleaning).
4. Seiketsu (Cleanliness).
5. Shitsuke (Discipline).

Westernized views of 5S are also common.[13] (Productivity_Press_Development_Team 1996)

1. Sort (Organization).
2. Set in Order (Orderliness).
3. Shine (Cleanliness).
4. Standardize (Standardized Cleanup).
5. Sustain (Discipline).

Figure 14 describes the steps within the 5S process.

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[12] 5S is also a key element in the implementation of Lean Manufacturing. 5S provides a structured approach to removing waste from shop floor work stations. [Pomorski, 2002 #908] As an example, Ford Motor Company includes 5S activity as a tool to achieve manufacturing stability in the first phase of their Lean Manufacturing implementation. Liker, J. K. (1998). Introduction: Bringing Lean Back to the USA. Becoming Lean: Inside Stories of U. S. Manufacturers. J. K. Liker. Portland, OR, Productivity Press.

[13] Another common western acronym for 5S activity is CANDOS (Cleanliness, Arrangement, Neatness, Discipline, Order, Safety). The CANDO process has been used quite effectively in the semiconductor industry. Howren, M. (1999). Implementing CANDOS to Change the Culture and Prepare for Autonomous Maintenance. 10th Total Productive Maintenance Conference, Las Vegas, NV, Productivity, Inc.
Ford, J., J. Kubicek, et al. (2000). SCANDOS= Safety #1 + CANDOS (5S): Engaging the Workforce. 11th Total Productive Maintenance Conference, Dallas, TX, Productivity, Inc. Gardner notes that CANDOS are used to involve every member of the workforce in safety and housekeeping and that at National Semiconductor every cubic foot of the production floor receives a CANDOS audit on a defined schedule. Gardner, L. (2000). Continuous Improvement through 100% Workforce Engagement. 11th Annual Total Productive Maintenance Conference and Exposition, Dallas, Productivity, Inc.

5S Description

5S Step	Description
Sort	Remove all items from the workplace that are not needed for current production (or clerical) operations. Excess material (waste)[14] at the work place can lead to errors and defects.
Set in Order	Arrange needed items so that they are easy to locate and use. Label them so that they are easy to find and put away.
Shine	Clean floors, equipment, and work stations. The Shine step of 5S also includes identifying and preventing the sources of contamination or dirt. Shine is integrated with daily maintenance tasks to maintain condition as pristine as possible.
Standardize	Create methods and practices to maintain Sort, Set in Order, and Shine on an ongoing and continuously improving manner.
Sustain	Make 5S an integral part of standard operating procedure.

Figure 14 - 5S Description

A common methodology used during the initial Sort phase of 5S is the Red-Tag Inspection, illustrated in Figure 15. The Red Tag process allows operators to identify the items that are required for production use at the workstation and provides an action path for appropriate storage or disposal of items not required at the workstation. Items that are not required immediately[15] for production at the workstation are red tagged for disposition. The red tagged items are then sent to the red tag holding area for further evaluation. In order to implement the red-tag strategy effectively, a red-tag holding area must be created. The holding area provides a location to dispose of the excess items appropriately and provides a safety net to hold items for a period of time before disposing of them. This provides a useful buffer it

[14] Ohno describes seven sources of waste in manufacturing (Overproduction, Time, Transportation, Processing, Inventory, Movement, and Defects). Excess inventory includes not only work in progress (WIP), but also manufacturing support supplies and tooling. Ohno, T. (1988). Toyota Production System. Portland, OR, Productivity Press. Elimination of waste is a driving concept of Lean Manufacturing. Pomorski, T. (2002). Lean Manufacturing: Concepts, History, and Literature Review. Cincinnati, OH, The Union Institute and University.
[15] A common rule of thumb is the "24 Hour Rule". Items that are used daily to support production remain at the workstation. Any item that is used less frequently than every day is removed for disposition.

the need for the item is not fully understood. (Productivity_Press_Development_Team 1996)

Although generally understood to be a valuable and critical element of the TPM process, it may be difficult to assess the economic value of the 5S activity. "The concepts that compromise 5S activities tend to be overly didactic. This is because the activities are not centered on results, but rather they emphasize people's behavioral patterns, such as the elimination of unnecessary items from the work environment or the cleaning and neatening of equipment. Consequently, the activities are of a kind that make quantitative assessment of their effectiveness difficult." (Takahashi and Osada 1990 p. 123)

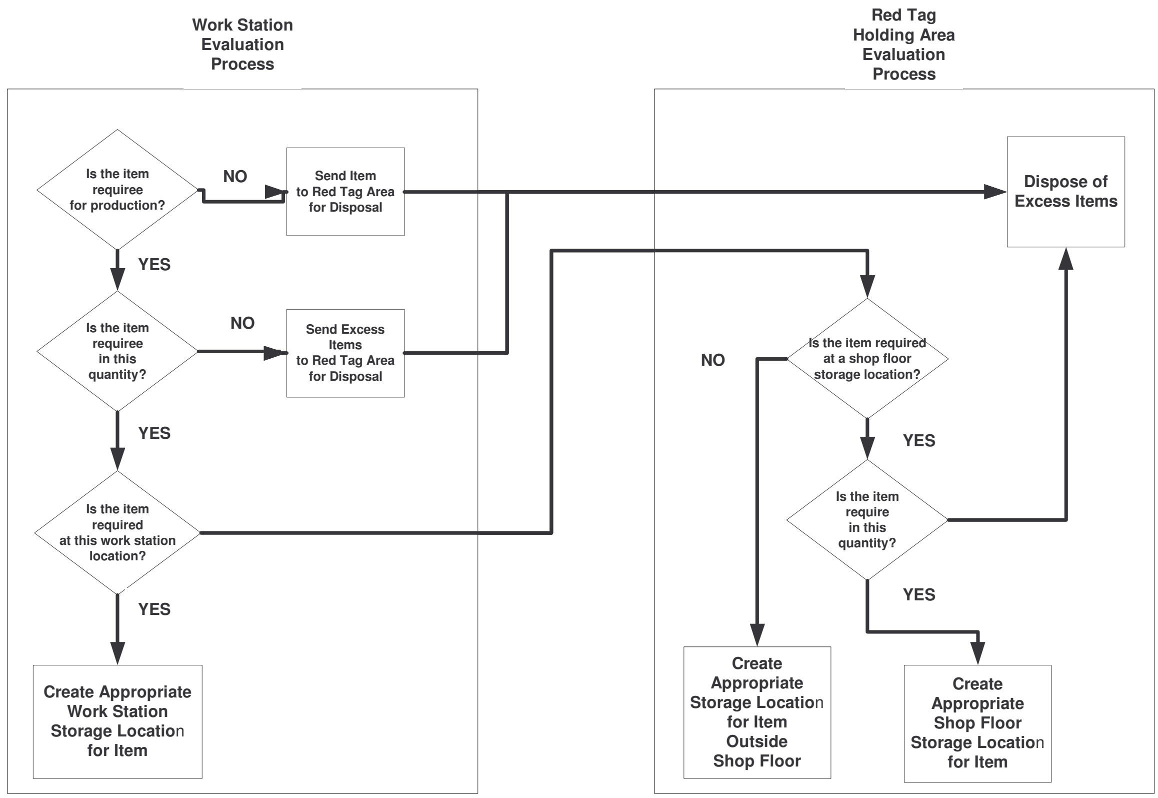

Figure 15 - Red Tag Decision Process

6.1.1.2.3 Manager's Model and Pilot Teams

A common approach to proliferating Autonomous Maintenance is through the Manager's Model and Pilot Teams. The Manager's Model and Pilot Teams develop individual Autonomous Maintenance skills, train leaders for Autonomous Maintenance teams, and demonstrate the effectiveness of Autonomous Maintenance implementation, and refine the Autonomous Maintenance implementation process. Wilmott describes objectives for the Manager's Model. (Willmott 1994)

1. Change employee attitudes (foster positive attitudes) about TPM.
2. Demonstrate the power of TPM implementation.
3. Prove and improve the TPM implementation process.

4. Show the results of effective teamwork.
5. Test the water – experiment with TPM methodologies.
6. Identify and address initial barriers to TPM implementation.
7. Build the local TPM policies and procedures.
8. Plan further TPM rollout and supporting infrastructure.

Leflar identifies four additional objectives of the Manager's Model and Pilot Teams. (Leflar 2001)

1. Take academic TPM and turn it into results.
2. Customize TPM activities to fit the organization.
3. Prove that TPM can be implemented successfully.
4. Develop and provide tools, procedures, and infrastructure for further TPM activity.

The importance of learning during the Manager's Model and Pilot Teams cannot be stressed enough. "Continuous learning is the heart of continuous improvement. Machines do only what people make them do – right or wrong – and can only perform better if people acquire new knowledge and skills regarding equipment care." (Leflar 1999 p. 10)

The proliferation of Autonomous Maintenance can be viewed as a series of cascading activities starting with the Manager's Model, as shown in Figure 16.

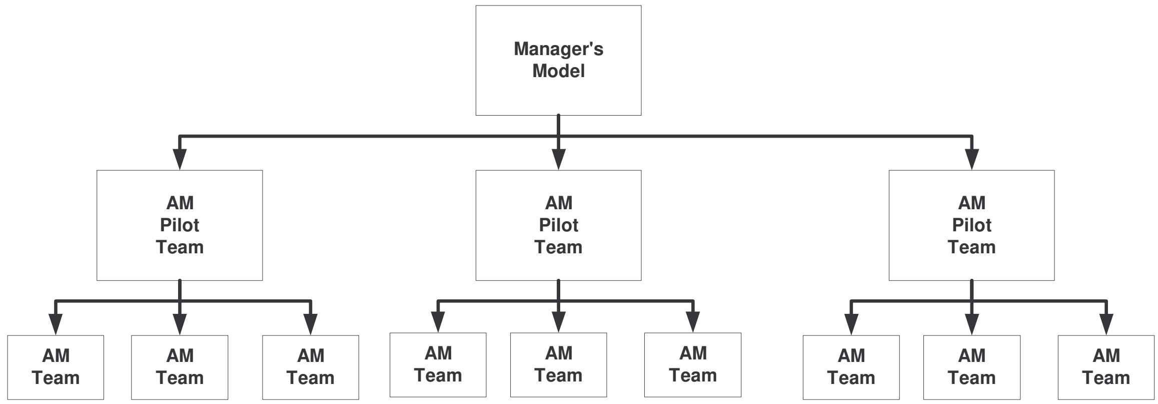

Figure 16 - Manager's Model and Pilot Teams

"The key to the establishment and development of the basic TPM plan is ensuring the support of the plan's priorities and activities by the top management who drive it forward. The most important point is how well the top and middle managers recognize the necessity for and future value of TPM activities." (Takahashi and Osada 1990 p. 21) One of the TPM tools to educate managers on Autonomous Maintenance methodology and to demonstrate the benefits of Autonomous Maintenance implementation is the Manager's Model. During the Manager's Model, the site management team engages in an Autonomous Maintenance project. Managers trained during the Manager's Model become the leaders of the subsequent Autonomous Maintenance Pilot Teams that continue Autonomous Maintenance proliferation in specific work areas.[16] "Many times a company will embark on a TPM journey to have it fail because it was not supported at a high enough organizational level or management failed to follow the manager's model of

[16] Depending on the size of the operation, there may be a number of Pilot Teams operating within a work area.

experiential tops down management involvement and participation." (Gardner 2000 p. 2) Likewise, the Pilot Teams spawn work area Autonomous Maintenance teams and provide training and experience for the leaders of those teams. Candidate equipment for Manager's Model and Pilot Team Autonomous Maintenance deployment should be selected with the following criteria in mind.

- The equipment and the results of the AM activity are visible to the employees.
- There is a high probability that AM activity will improve the performance of the equipment and the improvement will be meaningful to the operation.
- Improving equipment performance through AM activity presents sufficient challenge to validate the Autonomous Maintenance improvement process.

Leflar suggests that the best candidate is non-constraint (excess production capacity) equipment with a history of unreliable performance. (Leflar 2001) He notes that Pilot Team Autonomous Maintenance activity at Agilent Technology reduced equipment failures by 90%, increased equipment productivity by 50%, and reduced maintenance time within one year. (Leflar 2001)

6.1.1.2.4 Visual Controls

Visual controls can be defined as "visual or automated methods which indicate deviation from optimal conditions, indicate what to do next, display critical performance metrics, or control the movement and/or location of product or operation supplies." (Pomorski 1998 p. 17) Visual controls present to the manufacturing operator;

- WHAT the user needs to know.
- WHEN the user needs to know it.
- WHERE the user needs to see it.
- In a format that is CLEARLY UNDERSTOOD by the user.

Visual controls are varied and may be specific to a particular production environment. Some examples of visual controls include the following.

- Graphic Visual Controls.
  - Gauges and meters.
  - Kanban systems.
  - Slip marks.
  - Labels.
  - Storage or location identification.
  - Color-coding.
- Audio Visual Controls.
  - Alarms (sirens, buzzers, etc.).
  - Verbal (commands, warnings, etc.).
- Automated Visual Controls.
  - Closed-loop automation (detect and respond).

Visual controls play a key role in the 5S process by providing an effective tool to remove clutter and organize the workplace.

Activity boards are a specific type of visual control that is commonly utilized in TPM. JIPM refers to activity boards as a *guide to action*. They present the TPM team with "a visual guide to its activities that makes the [improvement activities] so clear that anyone can immediately understand them. (Japan_Institute_of_Plant_Maintenance 1997 p. 87) JIPM suggests that the activity board include the following components.

1. Team name, team members, and team roles (pictures).
2. Company policy and/or vision.
3. Ongoing results from team activities (charted by month).
4. The improvement theme addressed by the team activity. The current problems being solved.
5. The current situation and the causes.
6. Actions to address the causes and the effects of specific actions (annotated graphs where appropriate).
7. Improvement targets.
8. Remaining problems or issues for the team.
9. Future planned actions.

Figure 17 presents an example of a TPM activity board showing information pertinent to the team's continuous improvement activity.

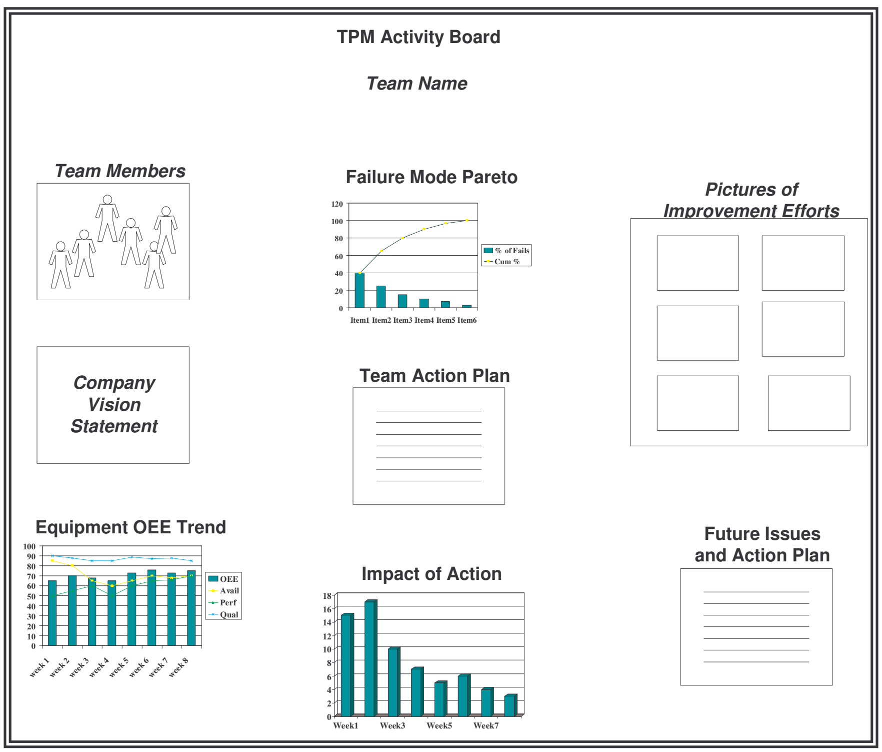

Figure 17 - Activity Board Example

Activity boards, used as a visual control for Autonomous Maintenance, provide the following functions. (Japan_Institute_of_Plant_Maintenance 1997)

- Visual guide to team improvement activities.
- Scorecard for improvement activity goals and activity effectiveness.
- Translate and present the company vision to employees.
- Encourage, support, and motivate the team members.
- Share learning between improvement teams.
- Celebrate team successes.

Activity boards are posted so that the employees easily access them. They are typically located in the work area or common areas where employees meet. (Pomorski 1997)

Another common visual control tool that is used in Autonomous Maintenance is the One Point Lesson (OPL).[17] Robinson and Ginder consider the OPL to be one of the most powerful tools for transferring skills. (Robinson and Ginder 1995) "A one-point lesson is a 5 to 10-minute self-study lesson drawn up by team members and covering a single aspect of equipment or machine structure, functioning, or method of inspection." (Japan_Institute_of_Plant_Maintenance 1997 p. 105) "Regarding education of operators, in many cases sufficient time cannot be secured for the purpose of education at one time or operators cannot acquire such learning unless it is repeated through daily practice. Therefore, study during daily work, such as during morning meetings or other time, is highly effective. One-point lessons are therefore a learning method frequently used during 'Jishu-Hozen' [Autonomous Maintenance]

[17] The One Point Lesson is also referred to as the Single Point Lesson (SPL) by some authors.

activities." (Japan_Institute_of_Plant_Maintenance 1996 p. 107) One-point lessons are:

- Tools to convey information related to equipment operation or maintenance knowledge and skills.
- Designed to enhance knowledge and skills in a short period of time (5-10 minutes) at the time they are needed.
- A tool to upgrade the proficiency of the entire team.

"The basic principle is for individual members to personally think, study, and prepare a sheet [one-point lesson] with originality and to explain its content to all the other circle members, to hold free discussions on the spot and to make the issue clearer and surer." (Japan_Institute_of_Plant_Maintenance 1996 p. 108) One-point lessons and are "one of the most powerful tools for transferring skills…The teaching technique helps people learn a specific skill or concept in a short period of time through the extensive use of visual images. The skill being taught is typically presented, demonstrated, discussed, reinforced, practiced, and documented in thirty minutes or less. Single-point lessons are especially effective in transferring the technical skills required for a production operator to assume minor maintenance responsibilities." (Robinson and Ginder 1995 p. 77)

Some key concepts of the one-point lesson are noted.

- The OPL is visual in nature. Pictures, charts, and graphics are emphasized rather than words.
- The OPL discusses a single topic or action being shared.

- The OPL is developed and researched by the employee doing the work to share learning with other employees doing the work.

- The creating employee at the workstation or during team meetings presents OPL's.

Leflar identifies the following significant themes for the effective development and use of one-point lessons. (Leflar 2001)

1. One-point lessons contain a single theme to be learned.
2. The information being shared should fit on one page.
3. OPL's contain more visual information than text.
4. Any text should be straightforward, easy to understand, and to the point.
5. When delivering the OPL, explain the need for the knowledge (what problem is being solved).
6. Design OPL's to be read and understood by the intended audience in 5-10 minutes.
7. Those who learn the OPL's continue to teach others.
8. OPLs are delivered at the workstation.
9. OPLs are retained for reference.

One-point lessons can share information on basic knowledge (fill in knowledge gaps and ensure people have knowledge needed for daily production), examples of problems (communicate knowledge or skills needed to prevent and resolve problems), or discussion of improvements to equipment or methods (communicate how to prevent or correct equipment abnormalities). (Japan_Institute_of_Plant_Maintenance 1997) After delivery, the one-point lessons become part of the operator training documentation. One-point lessons can also be included as attachments to equipment operating or maintenance specifications.

6.1.1.3 Planned Maintenance Pillar (PM)

The objective of Planned Maintenance is to "establish and maintain optimal equipment and process conditions". (Suzuki 1994 p. 145) As defined by JIPM, "Devising a planned maintenance system means raising output (no failures, no defects) and improving the quality of maintenance technicians by increasing plant availability (machine availability). Implementing these activities efficiently can reduce input to maintenance activities and build a fluid integrated system, which includes:

- Regular preventive maintenance to stop failures (Periodic maintenance, predictive maintenance).
- Corrective maintenance and daily MP [maintenance prevention] to lower the risk of failure.
- Breakdown maintenance to restore machines to working order as soon as possible after failure.
- Guidance and assistance in 'Jishu-Hozen' [Autonomous Maintenance]." (Japan_Institute_of_Plant_Maintenance 1996 p. 119)

Like Focused Improvement, Planned Maintenance supports the concept of zero failures. "Planned maintenance activities put a priority on the realization of zero failures. The aim of TPM activities is to reinforce corporate structures by eliminating all losses through the attainment of zero defects, zero failures, and zero accidents. Of these, the attainment of zero failures is of the greatest significance, because failures directly lead to defective products and a lower equipment operation ratio, which in turn becomes a major factor for accidents." (Shirose 1996 p. 309) Maintenance activity can be viewed as a continuum of regimes as illustrated in Figure 18.[18]

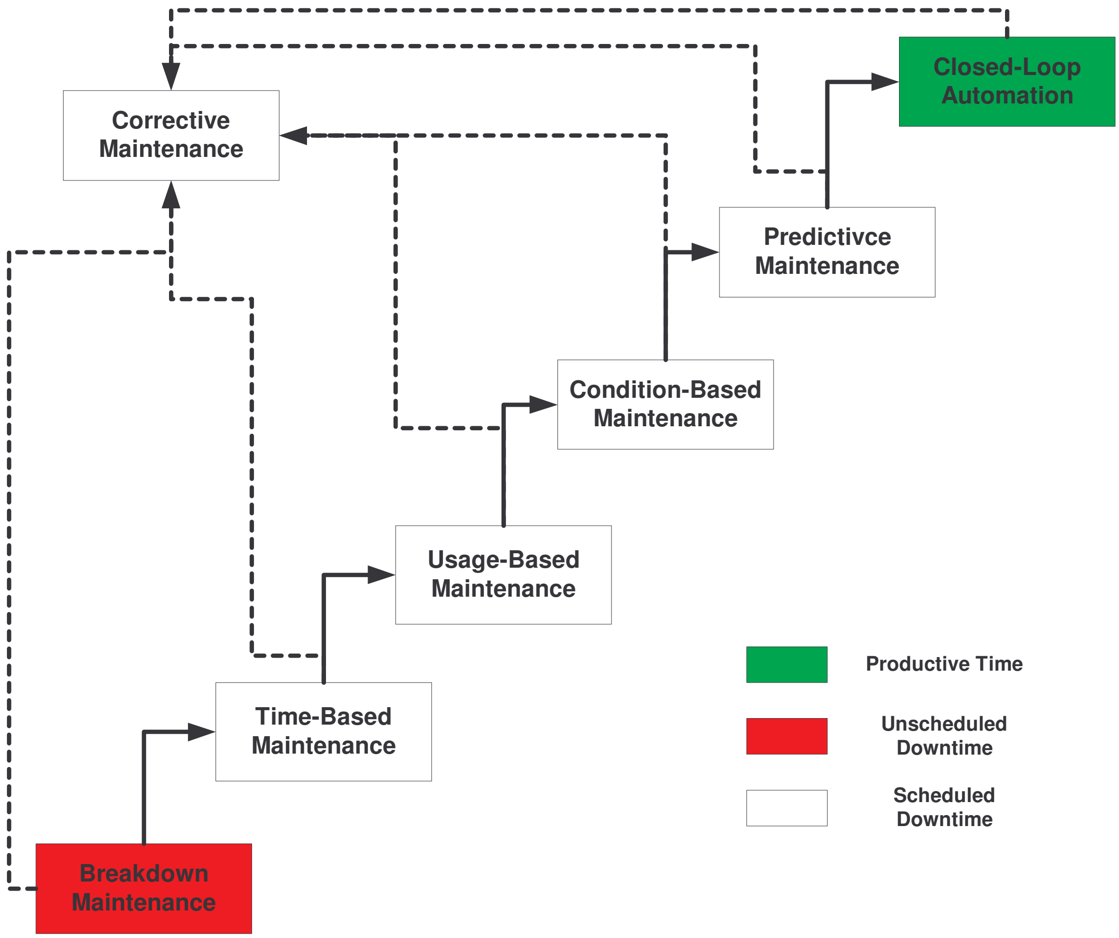

Figure 18- Maintenance Regimes

Breakdown Maintenance (BM): Breakdown Maintenance refers to maintenance activity where repair is performed following equipment failure/stoppage or upon a

[18] The maintenance regimes are color coded to represent the SEMI E10 equipment states. SEMI (2001). SEMI E10 Standard for Definition and Measurement of Equipment Reliability, Availability, and Maintainability (RAM). San Jose, CA, Semiconductor Equipment and Materials International.

hazardous decline in equipment performance.[19] (Japan_Institute_of_Plant_Maintenance 1996)

Time-Based Maintenance: Time-Based Maintenance[20] refers to preventive maintenance activity that is scheduled based on an interval of time (for instance daily, weekly, monthly, etc.) "Preventive maintenance … keeps equipment functioning by controlling equipment components, assemblies, subassemblies, accessories, attachments, and so on. It also maintains the performance of structural materials and prevents corrosion, fatigue, and other forms of deterioration from weakening them." (Suzuki 1994 p. 149)

Usage-Based Maintenance: Usage-Based Maintenance refers to preventive maintenance activity that is scheduled based on some measure of equipment usage (for example number of units processed, number of production cycles, operating hours, etc.) Usage-Based Maintenance is significantly different from Time-Based Maintenance in that it is scheduled based on the stress and deterioration that production activity places on equipment rather than just a period of time. Since equipment may run different levels of production from one time period to another,

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[19] Classic TPM strives for zero equipment failures, and thus considers any event that requires breakdown maintenance to be a continuous improvement opportunity. Nakajima, S. (1984). Introduction to TPM: Total Productive Maintenance. Cambridge, MA, Productivity Press.
Shirose, K., Ed. (1996). TPM-Total Productive Maintenance: New Implementation Program in Fabrication and Assembly Industries. Tokyo, Japan, Japan Institute of Plant Maintenance. Reliability-Centered Maintenance (RCM), on the other hand, allows equipment to run-to-failure (RTF) for some failure modes based on the economic and safety impact of the failure. Nowlan, S. F. and H. F. Heap (1978). Reliability Centered Maintenance. San Francisco, United Air Lines.
Moubray, J. (1991). Reliability Centered Maintenance. Oxford, England, Butterworth-Heinemann. A subsequent paper on Reliability-Centered Maintenance will examine this concept in more detail.

[20] Time-Based Maintenance is also known as Periodic Maintenance.

Usage-Based Maintenance allows preventive maintenance to be aligned with the actual workload placed on the equipment.

<u>Condition-Based Maintenance:</u> Condition-Based Maintenance is a form of preventive maintenance that is scheduled by actual variation or degradation that is measured on the equipment. Condition-Based Maintenance expands on the concept of Usage-Based Maintenance by scheduling maintenance based on observed (or measured) wear, variation, or degradation caused by the stress of production on equipment. Examples of monitored equipment parameters include vibration analysis, ultrasonic inspection, wear particle analysis, infrared thermography, video imaging, water quality analysis, motor-condition analysis, jigs/fixtures/test gauges, and continuous condition monitoring. (Leflar 2001) To execute Condition-Based Maintenance, the user must determine observation points or parameters to be measured that accurately predict impending loss of functionality for equipment. Observations and measurements are taken during scheduled inspection cycles. Visual controls play a role in Condition-Based Maintenance by providing graphic indications for out-of-specification measurements or conditions.

Leflar identifies two types of equipment degradation that should be considered when developing the site Planned Maintenance TPM pillar. (Leflar 2001)

- Graceful Deterioration: Degradation is gradual and the thresholds of acceptable performance can be learned and failures projected within scheduled inspection cycles (see Figure 19). Since the deterioration progresses slowly, the pre-failure degradation is identifiable within the scheduled Condition-Based Maintenance inspection cycles.

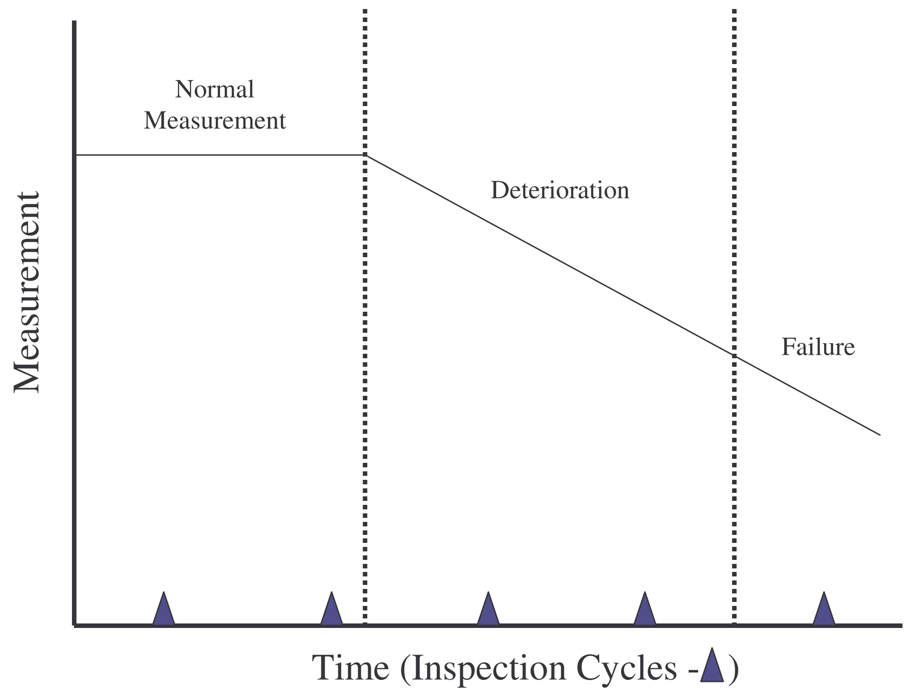

Figure 19 - Graceful Deterioration

- **Non-graceful Deterioration**: Deterioration progresses rapidly (from normal measurement to failure in less than the inspection cycle) and may not be detected within the inspection cycle of Condition-Based Maintenance (see Figure 20). Non-graceful deterioration may be learned, which allows the life expectancy of the component or function to be projected. In this case, Calendar-Maintenance Maintenance or Usage-Based Maintenance preventive maintenance scheduling will be effective.

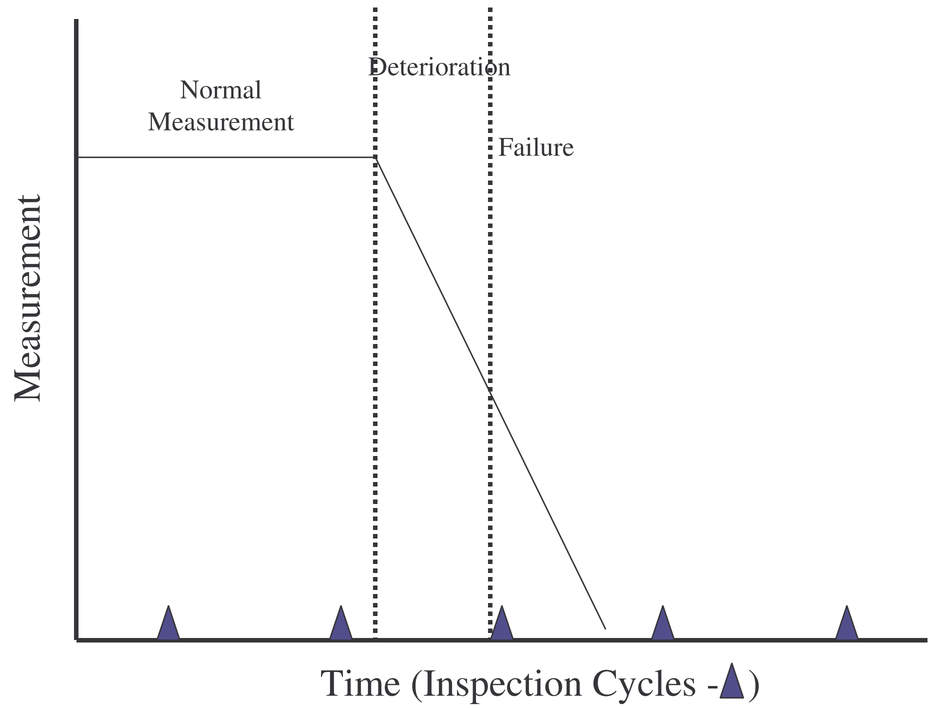

Figure 20 - Non-Graceful Deterioration

<u>Predictive Maintenance:</u> Predictive Maintenance takes Condition-Based Maintenance to the next level by providing real-time monitors for equipment parameters (for example voltages, currents, clearances, flows, etc.). "The objective of predictive maintenance is to prevent the function of equipment from stopping. This is done by monitoring the function or loss of performance of the parts and units of which equipment is composed, to maintain normal operation." (Nishinaga 1999 p. 13) Predictive Maintenance can be considered the 'crystal ball' of Planned Maintenance. (Steinbacher and Steinbacher 1993)

Predictive Maintenance "measures physical parameters against a known engineering limit in order to detect, analyze, and correct equipment problems before capacity reductions or losses occur…The key to the predictive method is finding the physical parameter that will trend the failure of the equipment." (Wireman 1991 p.87) Takeuchi refers to this as understanding the "pre-disease" (optimal operating) condition of the equipment so that variation from optimal can be identified. (Takeuchi 2001) Preventive maintenance is then scheduled when a monitored parameter is measured out-of-specification. Nhsinaga notes that the flow of predictive maintenance is divided into three broad elements, 1) establishment of diagnostic technologies (monitoring techniques), 2) diagnosis (comparing actual to target readings), and 3) maintenance action (responding to variation). (Nishinaga 1999) Where Condition-Based Maintenance occurs as the result of scheduled inspections, Predictive Maintenance identifies variation or degradation as it occurs and initiates maintenance activity.

Closed-Loop Automation: Simple Closed-Loop Automation describes an advanced automation capability in which equipment performance variation or degradation is monitored real-time and automated corrective input is made to the equipment (when possible within acceptable performance conditions) to adjust for the variation or degradation and continue normal in-specification processing (see Figure 21).

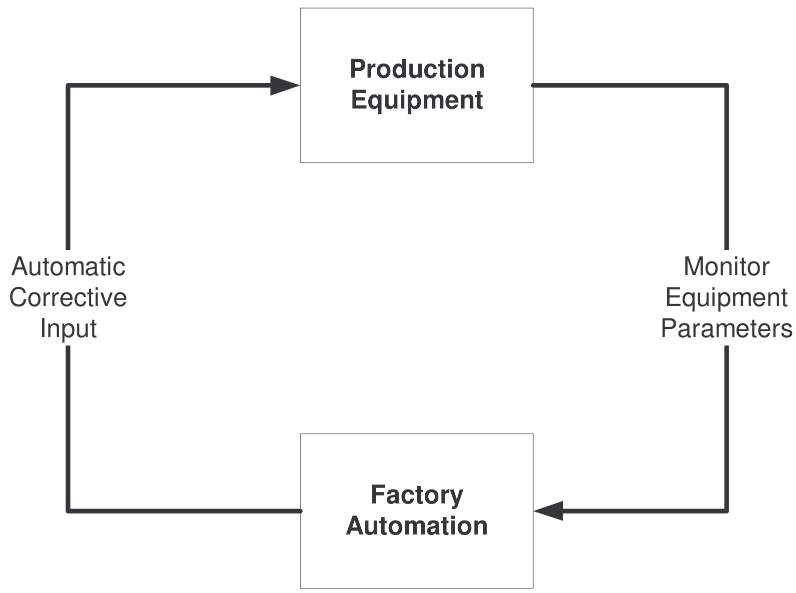

Figure 21 - Simple Closed-Loop Automation

Advanced Closed-Loop Automation[21] looks beyond just the equipment performance and monitors production flow as well as equipment, including the following functionality (see Figure 22). (Vadas and Walker 2003)

1. Sense changes.
2. Execute real-time decision logic acting on all data available to factory automation.
    a. Work in Progress (WIP).
    b. Maintenance Repair Operations (MRO).
    c. Production inventory.
    d. Resource capacity.
3. Issue work directives according to enterprise goals.
4. Coordinate equipment and material processing.
5. Continuously monitor and report status of equipment, material, and other factory resources.

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[21] A subsequent paper on Automation Engineering will examine Advanced Closed-Loop Automation in further detail.

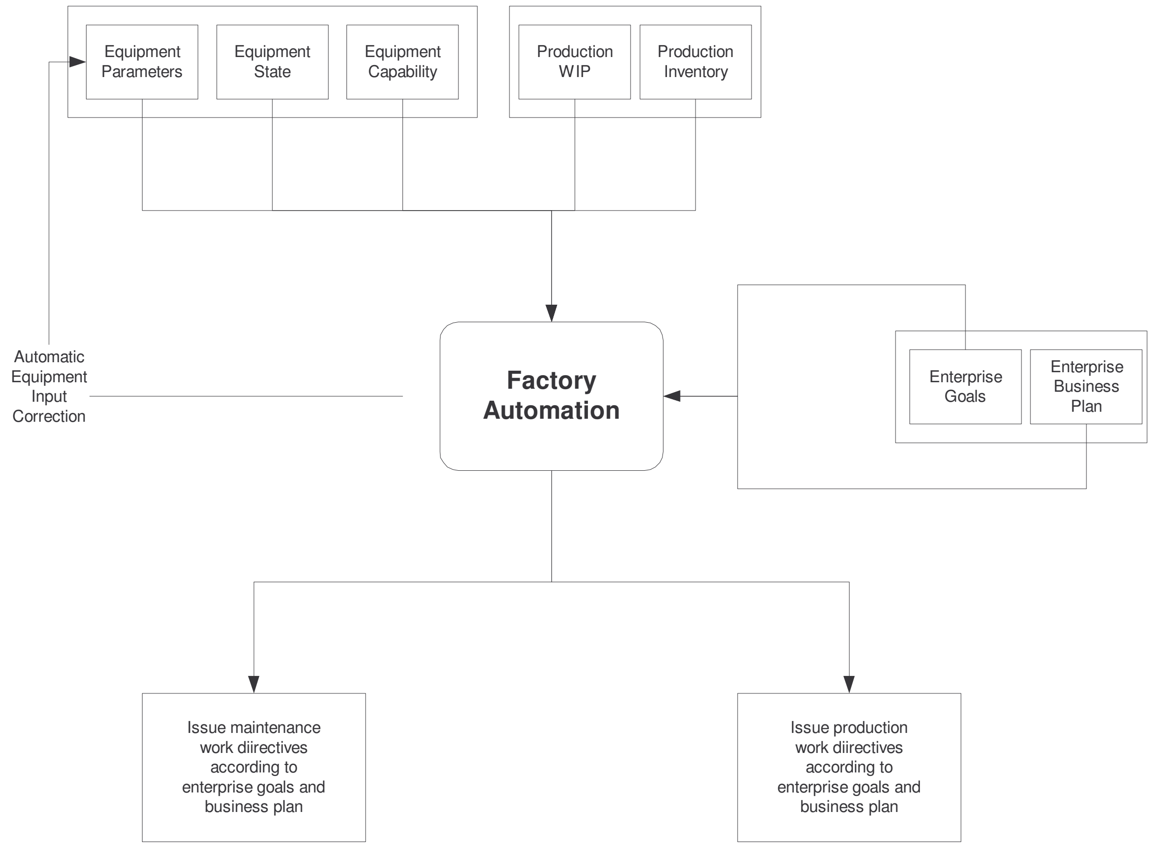

Figure 22 - Advanced Closed-Loop Automation

Corrective Maintenance: Corrective Maintenance is planned maintenance that makes *permanent* continuous improvement changes (versus repair activity) to equipment.[22] Within the TPM framework, identification of desirable corrective action activity occurs within the Focused Improvement, Autonomous Maintenance, and Planned Maintenance TPM pillar activity. Corrective Maintenance may reduce/eliminate failure modes, improve variation/degradation identification (visual controls), or simplify scheduled or unscheduled maintenance activity.

[22] In advanced automated manufacturing environments the concept of equipment maintenance is expanded to include supporting automation and automated material handling systems. No assumption is made as to actual internal organizational maintenance responsibilities.

The key to effective Planned Maintenance is to have a PM plan for every tool. The PM plan is based on the history and analysis of failure modes to determine preventive practices. The PM plan consists of five elements. (Leflar 1999)

1. A set of <u>checklists</u> for PM execution.
2. A <u>schedule</u> for every PM cycle.
3. <u>Specifications</u> and <u>part numbers</u> for every checklist item.
4. <u>Procedures</u> for every checklist item.
5. <u>Maintenance and parts log</u> (equipment maintenance history) for every machine.

The PM plan is then executed with precision; meaning that is implemented 100% of the time, completed 100% as specified, and implemented *without variation* by knowledgeable people. Leflar estimates that only 40% of all Planned Maintenance is accomplished with the expected degree of precision. "The precision level that will be achieved on any given maintenance task is 80% determined before a maintenance technician even begins the work! Management must supply the basic tools that create precision maintenance within their own organization." (Leflar 2000 p. 8) The PM plan is continually improved to make it easier, faster, and better. Equipment failures suggest the need for further improvement of the PM plan. To this end, two questions must be answered for every equipment failure post-mortem. (Leflar 2001)

1. Why did we not see the failure coming?
2. Why did the PM plan not prevent the failure?

Thomas presents a process for PM optimization that supports Leflar's concept of continuous PM process improvement (Figure 23). (Thomas 2003)

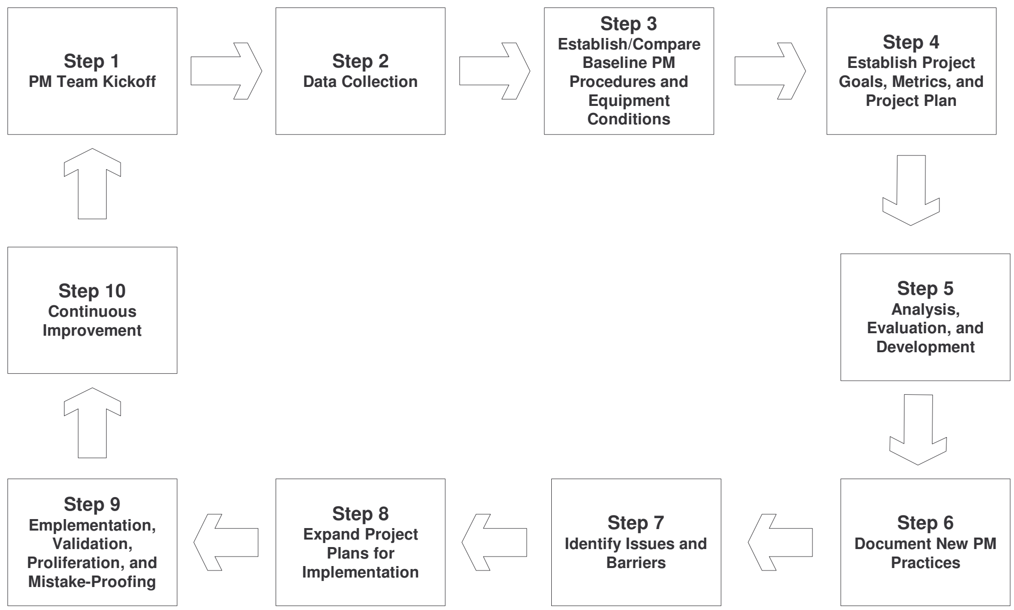

Figure 23 - PM Optimization Process

6.1.1.4 Maintenance Prevention Pillar (MP)

Maintenance Prevention refers to "design activities carried out during the planning and construction of new equipment, that impart to the equipment high degrees of reliability, maintainability, economy, operability, safety, and flexibility, while considering maintenance information and new technologies, and to thereby reduce maintenance expenses and deterioration losses." (Shirose 1996 p. 355) Maintenance Prevention is also known as Early Management (Suzuki 1994), Initial Phase Management (Shirose 1996), and Initial Flow Control (Nakajima 1984). The classic objective of MP is to minimize the Life Cycle Cost (LCC) of equipment. "In TPM, the concept of MP design is expanded to include design that aims at achieving not only no breakdowns (reliability) and easy maintenance (maintainability) but also prevention of all possible losses that may hamper production system effectiveness and pursuit of ultimate system improvement. To be specific, MP design should be so done as to satisfy reliability, maintainability, 'Jishu-Hozen', operability, resource-saving, safety, and flexibility." (Japan_Institute_of_Plant_Maintenance 1996 p. 103) Expanding the concept of Total Production Manufacturing, Maintenance Prevention applies to the design of equipment layout and facilitization as well as new processes and products (design for manufacturability).

Leachman identified time-to-market as a critical factor in the life-cycle profitability of new products/processes in the semiconductor industry. (Leachman, Plummer et al. 1999) Effective Maintenance Prevention supports reduction of the vertical startup lead-time by improving the initial reliability and reducing variability of equipment and processes. In large part, MP improvements are based on learning from the existing equipment and processes within the Focused Improvement, Autonomous Maintenance, and Planned Maintenance TPM pillar activities. "MP design activity minimizes future maintenance costs and deterioration losses of new equipment by taking into account (during planning and construction) maintenance data on current equipment and new technology and by designing for high reliability, maintainability, economy, operability, and safety. Ideally, MP-designed equipment must not break down or produce nonconforming products…The MP design process improves equipment [and process] reliability by investigating weaknesses in existing equipment [and processes] and feeding the information back to the designers." (Suzuki 1994 p. 201) For example, Agilent Technologies has maintenance technicians and engineers work directly with equipment manufacturers to share current equipment performance information to improve the design of new equipment. (Leflar 2003) One of the goals of MP design is to break free of equipment-centered design mentality by adopting a human-machine[23] system approach. (Suzuki 1994) In addition to equipment/process reliability and performance attributes, the systems approach will also look at the man-machine interface as it relates to operability and maintainability and safety.

6.1.1.5 Quality Maintenance Pillar

"Quality maintenance, in a nutshell, is establishment of conditions that will preclude the occurrence of defects and control of such conditions to reduce defects to zero." (Japan_Institute_of_Plant_Maintenance 1996 p. 134) Quality Maintenance is achieved by establishing conditions for 'zero defects', maintaining conditions within specified standards, inspecting and monitoring conditions to eliminate variation, and executing preventive actions in advance of defects or equipment/process failure. The key concept of Quality Maintenance is that it focuses on preventive action 'before it happens' (cause oriented approach) rather than reactive measures 'after it happens' (results oriented approach). (Japan_Institute_of_Plant_Maintenance 1996) Quality Maintenance, like Maintenance Prevention, builds on the fundamental learning and structures developed within the Focused Improvement, Autonomous Maintenance, Planned Maintenance, and Maintenance Prevention TPM pillars. Quality

[23] See Pomorski, T. (2002). Applying Sociotechnical Systems (STS) Theory to Advanced Manufacturing Operations. Cincinnati, OH, Union Institute and University. for discussion of human-machine and sociotechnical systems concepts.

Maintenance supports a key objective of TPM - ensuring that equipment and processes are so reliable that they *always* function properly. (Schonberger 1986)

The core concept of Quality Maintenance is integrating and executing the structures, practices, and methodologies established within Focused Improvement, Autonomous Maintenance, Planned Maintenance, and Maintenance Prevention. Quality Maintenance occurs during equipment/process planning and design, production technology development, and manufacturing production and maintenance activity. (Shirose 1996) "The precondition for implementation of quality maintenance is to put the equipment, jigs, and tools for ensuring high quality in the manufacturing process, as well as processing conditions, human skills, and working methods, into their desired states." (Shirose 1996 p. 395) Pre-conditions for successful Quality Maintenance implementation include abolishment of accelerated equipment deterioration, elimination of process problems, and the development of skilled and competent users. (Shirose 1996)

Figure 24 provides an illustration of the integration of TPM pillars to support Quality Maintenance.[24]

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[24] A detailed discussion of the TPM Training and Education pillar is not included in this paper. The objective of Training and Education is to create and sustain skilled operators able to effectively execute the practices and methodologies established within the other TPM pillars. The Training and Education pillar establishes the human-systems and structures to execute TPM. Training and Education focuses on establishing appropriate and effective training methods, creating the infrastructure for training, and proliferating the learning and knowledge of the other TPM pillars. Training and Education may be the most critical of all TPM pillars for sustaining the TPM program in the long-term. "A test of TPM success is to look at organizational learning, TPM is about continual learning." Leflar, J. (2003). TPM Interview. T. Pomorski. Fort Collins, CO.

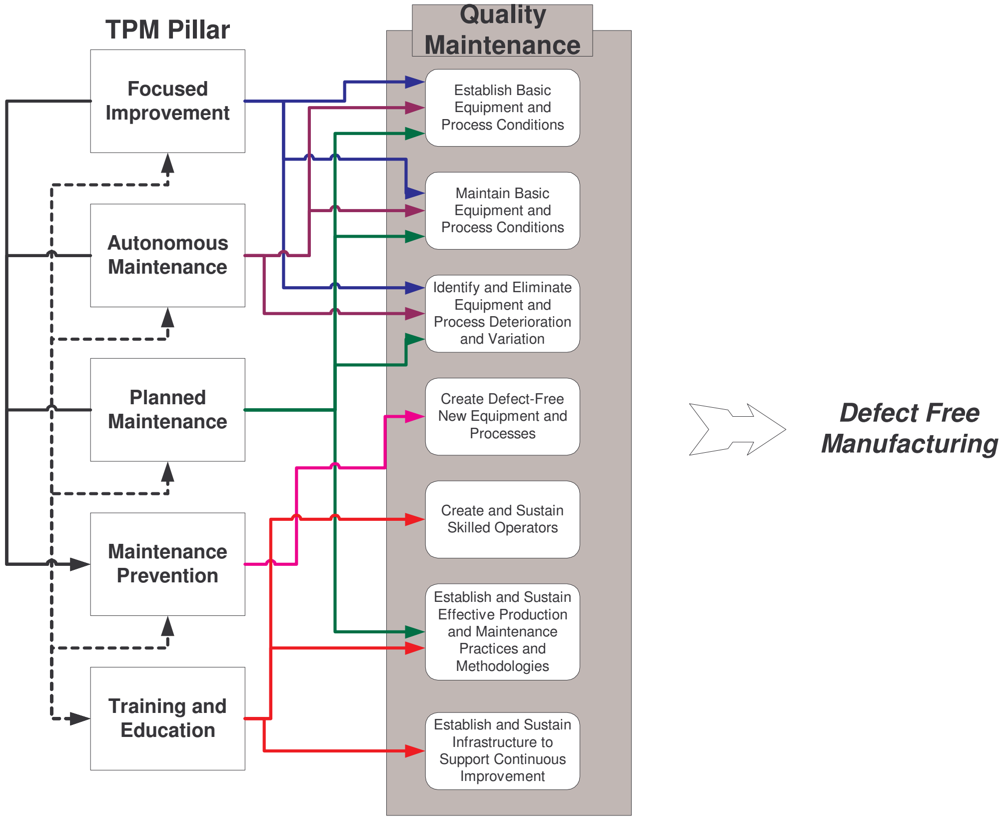

Figure 24 - Quality Maintenance Integration

6.1.1.6 Administrative TPM Pillar

Administrative TPM applies TPM activities to continuously improve the efficiency and effectiveness of logistic and administrative functions. These logistic and support functions may have a significant impact on the performance of manufacturing production operations. Consistent with the view of a 'production system' that includes not only manufacturing, but also manufacturing support functions, TPM must embrace the entire company, including administrative and support departments. Manufacturing is not a stand-alone activity, but is now fully integrated with, and dependent on, its support activities. "These departments increase their productivity by documenting administrative systems and reducing waste and loss. They can help raise production-system effectiveness by improving every type of organized activity that supports production." (Suzuki 1994 p. 284) Like equipment effectiveness improvement[25] Administrative TPM focuses on identifying and eliminating effectiveness losses in administrative activities. Figure 25 illustrates the type of effectiveness losses that are addressed in Administrative TPM. (Suzuki 1994) Implementing Administrative TPM is similar to equipment/process related TPM continuous improvement. The methodologies used in Focused Improvement, Autonomous Maintenance, Planned Maintenance, Maintenance Prevention, and Quality Maintenance are applied to administrative and support tasks and activity. Training and Education, of course, supports Administrative TPM also.

[25] See section 6.2 for discussion of Overall Equipment Effectiveness/Overall Equipment Efficiency and losses.

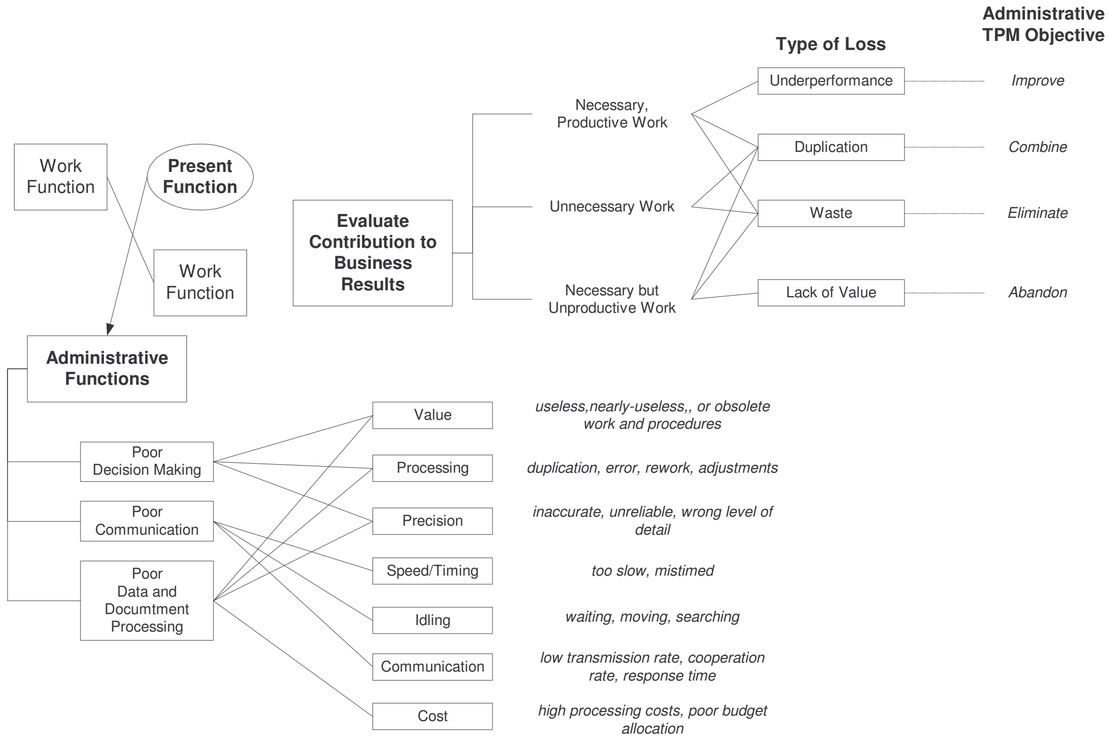

Figure 25 - Administrative TPM Effectiveness Losses

6.1.1.7 Safety and Environmental Pillar

Although shown as the last pillar of TPM (Figure 3), the TPM Safety and Environmental pillar is equally, if not more, important than the seven others. Shirose describes safety as "the maintenance of peace of mind". (Shirose 1996 p. 500) No TPM program is meaningful without strict focus on safety and environmental concerns. "Ensuring equipment reliability, preventing human error, and eliminating accidents and pollution are the key tenets of TPM." (Suzuki 1994 p. 323) Suzuki provides examples of how TPM improves safety and environmental protection.

- Faulty or unreliable equipment is a source of danger to the operator and the environment. The TPM objective of Zero-failure and Zero-defects directly supports Zero-accidents.
- Autonomous Maintenance teaches equipment operators how to properly operate equipment and maintain a clean and organized workstation. 5-S activity eliminates unsafe conditions in the work area.
- TPM-trained operators have a better understanding of their equipment and processes and are able to quickly detect and resolve abnormalities that might result in unsafe conditions.
- Operation of equipment by unqualified operators is eliminated through effective deployment of TPM.
- Operators accept responsibility for safety and environmental protection at their workstations.
- Safety and environmental protection standards are proliferated and enforces as part of the TPM Quality Maintenance pillar.

Implementing the TPM Safety and Environmental pillar focuses on identifying and eliminating safety and environmental incidents. According to the Heinrich Principle, (Heinrich 1980), for every 500,000 safety incidents there are 300 'near misses', 29 injuries, and 1 death, see Figure 26. Investigating industrial accidents, Heinrich found that 88% of accidents where caused by unsafe acts of people, 10% where the result of unsafe physical conditions, and 2% he considered 'acts of God'.

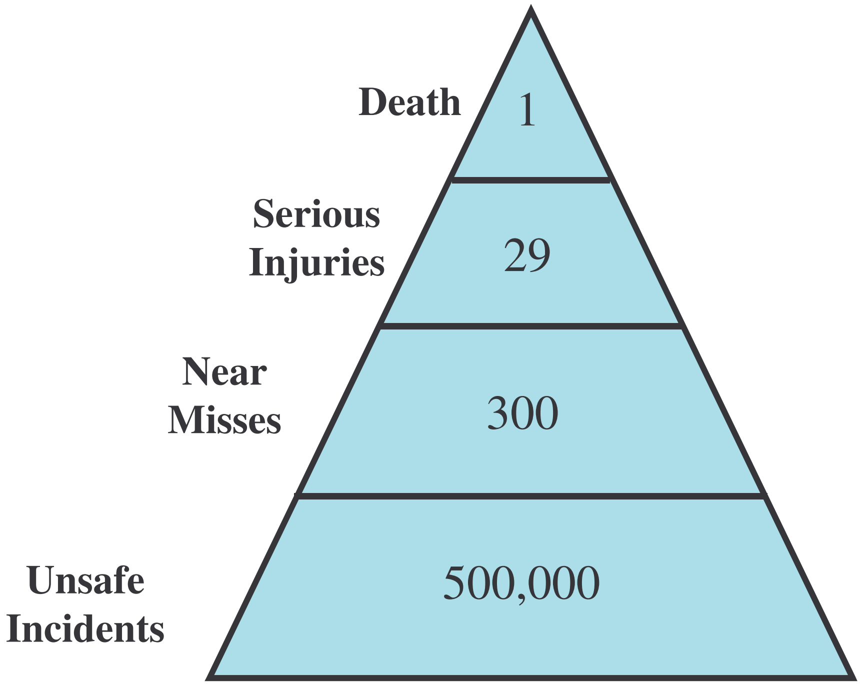

Figure 26 - The Heinrich Principle

TPM uses Why-Why Analysis[26] to probe for the root causes (incidents in the Heinrich model) that result in safety or environmental near misses. Suzuki describes

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[26] Why-Why Analysis is also known as 5-Why Analysis. It is a brainstorming root cause analysis (RCA) process that looks at a problem and searches for causes by asking 'Why?'. The simple flow of the process is illustrated below.

1. Identify the problem.
2. List the possible causes of the problem (the first level of Why).
3. Continue to as Why for each cause until there are no more suggestions.
4. Identify solutions for the lowest level of Why's (the root causes).

Typically, 5 levels of Why will lead the brainstorming team the root cause of a problem. For a more detailed explanation of Why-Why Root Cause Analysis see Asaka, T. and K. Ozeki (1990). Handbook of Quality Tools, The Japanese Approach. Cambridge, MA, Productivity Press.. "Such exploration of real causes should lead to improved methods to prevent recurrence." Japan_Institute_of_Plant_Maintenance, Ed. (1996). TPM Total Productive Maintenance Encyclopedia. Tokyo, Japan Institute of Plant Maintenance.

six phases that an operation passes through during an industrial accident. (Suzuki 1994)

- Phase 1 – Normal operation, stable state.
- Phase 2 – Signs of abnormality, the system becomes more and more disordered.
- Phase 3 – Unsteady state, difficult to restore to normal.
- Phase 4 – Obvious danger as a result of failure or abnormality. Damage and injury can still be contained and minimized.
- Phase 5 – Injury and severe damage occur.
- Phase 6 – Recovery after the situation is under control.

TPM practices, such as those listed below, allow quick operator intervention and prevent incidents from approaching Phase 3.

1. Monitor equipment and processes and quickly correct abnormalities.
2. Install and check safety equipment.
3. Identify and eliminate hidden equipment abnormalities and defects.

Environmental safety is becoming an increasing point of focus for TPM implementation. “Manufacturing management in the 21st century will not be effective if the environmental issues are ignored. Manufacturing management that does not take environmental issues into consideration will be removed from society. One of the causes of environmental issues is that industries, academic institutions, and government agencies have been specialized in research, development, promotion, and diffusion of design technologies to produce more artificial products. There is very little concern about setting conditions for equipment to the most favorable ones after it is put into operation or diagnostic techniques to maintain those conditions.”

(Ichikawa 1999 p. 9) Environmental safety goes beyond simply eliminating accidents. In today's manufacturing environment, environmental safety includes reduction of energy consumption, elimination of toxic waste, and reduction of raw material consumption. Funahashi describes a case study that uses TPM activity to reduce energy consumption in manufacturing. (Funahashi 1998)

Ichikawa proposes that TPM address the following key environmental objectives within the Safety and Environmental pillar. (Ichikawa 1999)

1. Construct an Environmental Management System (EMS) that integrates environmental issues as a system. This objective is consistent with ISO14001/14004.
2. Implement activities, through the TPM program, to reduce the environmental impact of manufacturing operations.
3. Create systems to reduce the environmental impact of manufacturing product and process development.
4. Enhance the environmental awareness and education of all employees.

Ichikawa emphasizes that the Environmental Management System "is part and parcel of the work and this implementation should be done through TPM. In concrete terms, this consists of environmental education, products and equipment development that implement improvements for environmental aspects reduction and give consideration to environmental load, and it is considered to be appropriate to develop these themes along the conventional TPM pillars." (Ichikawa 1999 p. 13)

6.1.2 The TPM Implementation Process

A core concept of TPM is that its implementation is based on a defined, structured, and repeatable implementation process. Elliott, discussing the development of world-class organizational performance, notes, "Winning requires an institutionalized management-proof process that is sustainable despite changes in leadership, strategy, and business conditions…" (Elliott 2001 p.7) He continues to say that "Manufacturing perfection is like any other form of excellence: It is a very defined combination of doing the right thing and doing it in an extraordinary manner." (Elliott 2001 p. 9) Nakajima developed the classic twelve-step TPM implementation process (Nakajima 1984; Nakajima 1988; Nakajima 1989) that has been the foundation for TPM implementation since 1984 (see Figure 27)[27]. Numerous TPM practitioners have suggested their own version of a TPM implementation process, however, most are a variation or simplification of the Nakajima model.

TPM Implementation Phase	TPM Implementation Step	Key Points	Actions
Preparation	1. Formally announce the decision to introduce TPM.	▪ Top management announcement of TPM introduction at formal meeting and through newsletter.	▪ Top management TPM overview training. ▪ TPM case studies or pilot team results. ▪ TPM readiness assessment. ▪ Top management buy-in. ▪ Top management commitment to TPM implementation.
Preparation	2. Conduct TPM introductory education and	▪ Senior management group training. ▪ Slide-show overview presentation for	▪ Management training. ▪ TPM philosophy promotion to employees.

[27] The first three columns (Phase, Step, Key Points) of the table are based on the Nakajima TPM implementation process Nakajima, S. (1984). Introduction to TPM: Total Productive Maintenance. Cambridge, MA, Productivity Press.
Nakajima, S. (1988). Introduction to Total Productive Maintenance. Cambridge, MA, Productivity Press.
Nakajima, S. (1989). TPM Development Program: Implementing Total Productive Maintenance. Portland, OR, Productivity Press.. The fourth column (Actions) expands on the Nakajima model by adding specific actions developed by the SEMATECH TPM Steering Committee. SEMATECH-International (1998). SEMATECH Total Productive Manufacturing (TPM) Implementation Guide. Austin, TX, SEMATECH.

TPM Implementation Phase	TPM Implementation Step	Key Points	Actions
	publicity campaign.	presentation for remaining employees.	▪ TPM Overview and management responsibility presentation to all management levels. ▪ Presentation of TPM overview to all employees.
Preparation	3. Create a TPM promotion organization.	▪ TPM Steering Committee and specialist subcommittees. ▪ TPM Promotions Office.	▪ Create a TPM Steering Committee composed of top management representing all functions. ▪ Identify and staff a TPM Promotion Office reporting to top management. Promotion Office to include a TPM Coordinator, TPM Facilitator(s) (1 per 12 teams), and a TPM content expert. ▪ Identify TPM champion(s) and their responsibilities. ▪ Determine mission and strategy. ▪ Include TPM in the business plan. ▪ Develop TPM step-by-step plan. ▪ Determine TPM education sourcing. ▪ Establish the TPM budget. ▪ Create TPM pillar subcommittees (chairman). ▪ Train the TPM trainer. ▪ Pilot project training for supervisors and managers. ▪ TPM facilitator training (include supervisors).

TPM Implementation Phase	TPM Implementation Step	Key Points	Actions
Preparation	4. Establish basic TPM policies and goals.	▪ Set baselines and targets.	▪ Determine TPM initiative objectives. ▪ Define TPM policies. ▪ Define OEE methodology and loss category definitions. ▪ Implement data collection system. ▪ Create OEE data reporting mechanism. ▪ Acquire data from the current source of data. ▪ Determine bottleneck (constraint) operations and equipment. ▪ Determine pilot project tool(s). ▪ Select sponsor(s) for pilot project(s). ▪ Determine the TPM compensation, reward, and recognition system.
Preparation	5. Draft a master plan for implementing TPM.	▪ Master plan from preparation stage to application for TPM prize.	▪ Create the TPM sustaining plan. ▪ Define basic skills required. ▪ Training course development. ▪ Created a timeline (3 to 5 years) for each planned TPM activity in Steps 7 to 12.
Introduction	6. Kick off the TPM initiative.	▪ Master plan from preparation stage to application for TPM prize.	▪ Top management presents the TPM policies, goals, and master plan to all employees. ▪ Ensure long-term commitment of the management team.

TPM Implementation Phase	TPM Implementation Step	Key Points	Actions
Implementation	7. Establish a system for improving production efficiency. **Focused Improvement Pillar** **Autonomous Maintenance Pillar** **Planned Maintenance Pillar** **Education and Training Pillar**	▪ Conduct Focused Improvement activities. ▪ Establish and deploy the Autonomous Maintenance program. ▪ Implement the Planned Maintenance program. ▪ Conduct operation and maintenance skill training.	▪ Team skills training. ▪ Problem solving skills training. ▪ Communication skills training. ▪ Business meeting skills training. ▪ Project management skills training. ▪ TPM process training. ▪ TPM activity board training. ▪ Establish cross-team communications. ▪ Structure team communication to management. ▪ OEE training. ▪ Launch team projects. ▪ Establish TPM process audits. ▪ Execute mid-project project progress reviews (progress, problems, plans, learning). ▪ Establish and execute periodic team reports to management. ▪ Establish cost savings analysis (ROI) for team projects. ▪ Identify, demonstrate, and communicate contribution to customer success. ▪ Share success stories with other teams and management. ▪ Establish end-of-project reviews. ▪ Implement standard procedures and methodologies for Visual Controls and One Point Lessons. ▪ Renew and repeat cycle.
Implementation	8. Establish and deploy the	Develop optimal vertical startup for products, processes, and equipment.	TPM team training.

TPM Implementation Phase	TPM Implementation Step	Key Points	Actions
	Maintenance Prevention activities. **Maintenance Prevention Pillar**		
Implementation	9. Establish Quality Maintenance systems. **Quality Maintenance Pillar**	Establish, maintain, and control conditions for zero failures, zero defects, zero accidents.	TPM team training.
Implementation	10. Create systems for eliminating efficiency losses in administrative and logistic functions. **Administrative Maintenance Pillar**	▪ Increase production support efficiency. ▪ Improve and streamline administrative and office functions.	▪ TPM team training. ▪ Proliferate throughout the company.
Implementation	11. Create the systems for managing health, safety, and the environment. **Safety and Environmental Pillar**	Create systems to ensure zero safety and environmental accidents.	TPM team training.
Consolidation and Sustaining	12. Sustain full TPM implementation and continually improve the TPM process.	▪ Raise TPM team goals. ▪ Establish ongoing audits. ▪ Apply for JIPM TPM Prize (optional)	▪ Review and raise the TPM team goals. ▪ Understand and attain JIPM TPM Prize criteria. ▪ Audit the TPM process.

Figure 27 - TPM Implementation Process

A detailed implementation process for each of the twelve steps is further suggested. These step implementation processes are described in a number of TPM texts. (Nakajima 1984; Nakajima 1988; Nakajima 1989; Suzuki 1994; Shirose 1996) SEMATECH developed a TPM assessment and audit guide that provides a rating system to measure the effectiveness of implementation for each of the twelve steps. (SEMATECH-International 1996)

Productivity, Inc. proposes a TPM rollout plan that incorporates and expands on the Nakajima TPM implementation process, Figure 28.[28] (Productivity 1999)

[28] I have noted the steps in the Productivity, Inc. TPM roll-out plan that relate to specific TPM pillars in the Nakajima model (Figure 3 - TPM Pillars (Nakajima Model) in brackets. Although the Quality Maintenance and Safety and Environmental pillars are not specifically noted, they are inherent in activities related to Focused Improvement, Autonomous Maintenance, Planned Maintenance, and Maintenance Prevention. Education and Training is, of course, associated with all of the TPM activities.

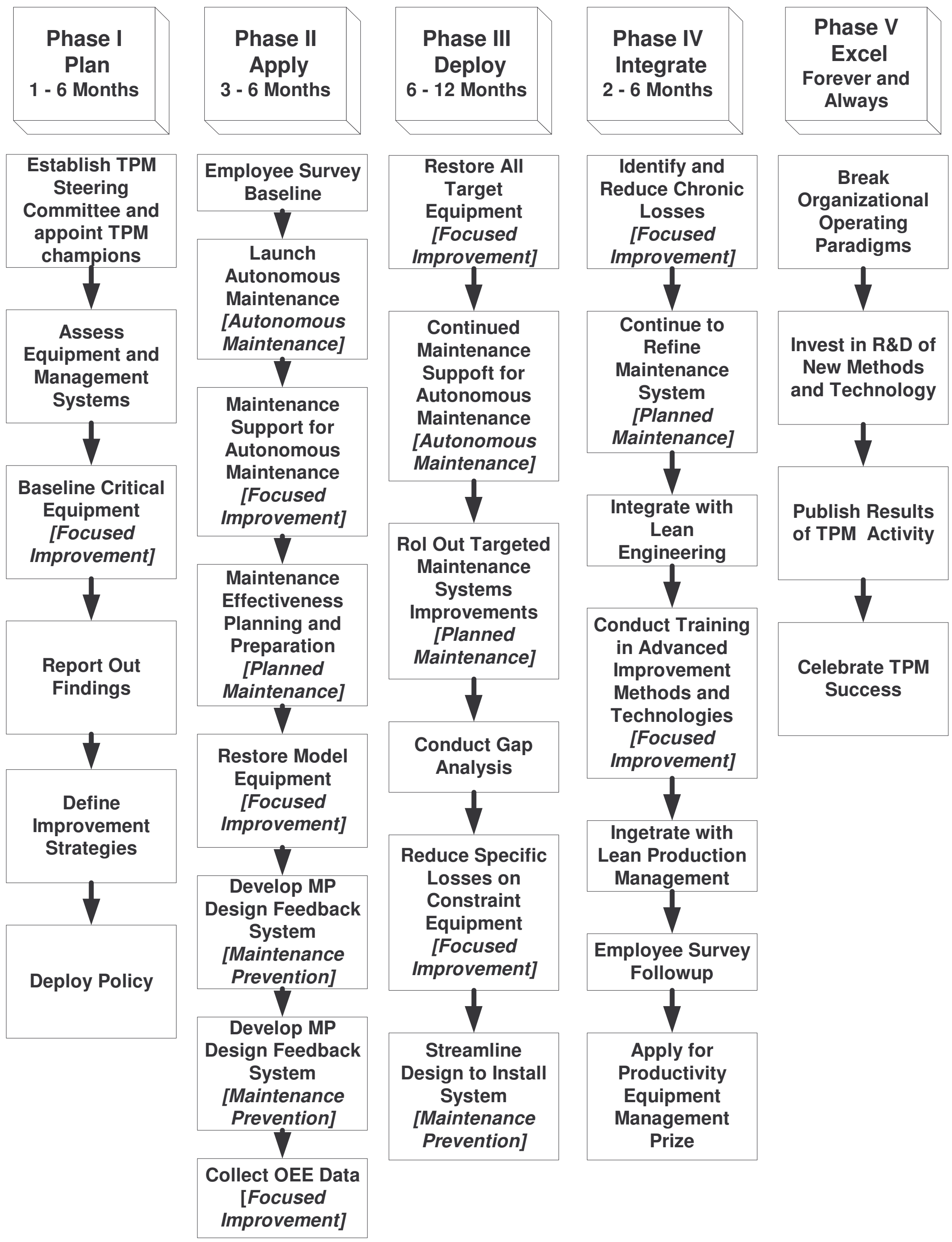

Figure 28 - Productivity, Inc. TPM Roll-out Plan

As frequently cited, companies alter the TPM implementation process to meet their own needs. Thomas summarizes this approach and says, "…traditional processes still provide the best chance of success. That is not to say, however, that short cuts do not exist. I find that the best way of identifying short cuts is to first perform a pilot using traditional processes and tools. Only then can one best identify where to cut corners and where it is vital to take the extra time and use the extra resources to realize the desired benefits." (Thomas 2003 p. 5)

Leflar suggests an example of a simplified TPM implementation process. (Leflar 2001)

1. Restore equipment to 'new' condition. [Focused Improvement and Autonomous Maintenance]
    a. Ensure that equipment is clean and free of humanly detectable minor defects.
    b. Create cleaning and inspection standards to keep machines in this condition.
    c. Create visual controls to rapidly identify variation from this condition.
2. Identify and complete maintenance plans. [Planned Maintenance]
    a. Create PM checklists.
    b. Establish schedules for PM execution.
    c. Create PM procedures.
    d. Specify equipment inspection procedures.
    e. Identify and standardize equipment replacement parts.
    f. Create equipment parts logs.
    g. Implement equipment quality checks.
3. Implement maintenance plans ***with precision***. [Quality Maintenance]
    a. Complete ***all*** PM's on time.
    b. Complete 100% of PM checklist items.
    c. Execute PM checklists without variation.
    d. Continually advance the knowledge and skill of the factory personnel.
4. Prevent recurring machine failure.
    a. Implement failure analysis to prevent recurring failure.
    b. Establish continuous PM evaluation and improvement (make PM's easier, faster, better).
5. Improve machine productivity with the following methods.
    a. Lubrication analysis.
    b. Calibration and adjustment analysis.
    c. Quality maintenance analysis.

d. Machine part analysis.
e. Condition-of-use and life analysis.
f. Productivity analysis.
g. Extended condition monitoring.
h. Continuous condition monitoring.
i. Maintenance cost analysis.

Hartmann provides another TPM implementation process that simplifies the Nakajima implementation model. (Hartmann 1992)

Phase I – Improve equipment to its highest required level of performance and availability. [Focused Improvement]

- Determine existing equipment performance and availability – current OEE.
- Determine equipment condition.
- Determine current maintenance performed on equipment.
- Analyze equipment losses.
- Develop and rank equipment improvement needs and opportunities.
- Develop setup and changeover improvement needs and opportunities.
- Execute improvement opportunities as planned and scheduled activity.
- Check results and continue with improvement as required.

Phase II – Maintain equipment at its highest required level of performance and availability. [Autonomous Maintenance, Planned Maintenance, Quality Maintenance]

- Develop planned maintenance, cleaning, and lubrication requirements for each machine.
- Develop planned maintenance, cleaning, and lubrication procedures.
- Develop inspection procedures for each machine.

- Develop planned maintenance, lubrication, cleaning and inspection systems, including all forms and controls.
- Develop planned maintenance manuals.
- Execute planned maintenance, cleaning and lubrication as planned and scheduled activities.
- Check results and apply corrections to system as required.

Phase III – Establish procedures to purchase new equipment and develop new processes with a defined level of high performance and low life cycle cost. [Maintenance Prevention, Quality Maintenance]

- Develop engineering specifications.
- Get feedback from production operations based on current equipment experience.
- Get feedback from maintenance operations based on current equipment experience.
- Eliminate past problems in new equipment and process technology design.
- Design in diagnostic capabilities with new equipment and processes.
- Start training on new equipment and processes early (prior to deployment).
- Accept and deploy new equipment and processes only it they meet or exceed engineering specifications.

The TPM implementation process, at the highest level then, is simply initialization, implementation, and institutionalization. (Steinbacher and Steinbacher 1993)

6.2 Overall Equipment Effectiveness

As noted previously, Overall Equipment Effectiveness (OEE) is the TPM metric for measuring equipment effectiveness or productivity. "A company cannot make business gains solely by using cost cutting measures because it cannot cut costs enough to become a world-class competitor. Instead it must invest resources in productivity improvement. This generally increases factory throughput and cuts cost at the same time." (Leflar 2001 p. 9) Variations for calculating OEE are in use, however, most are consistent in identifying three major elements of OEE.

- **Availability** – the effectiveness of the operation to make equipment available to perform production activity.
- **Performance –** the effectiveness of the operation to execute production activity during the period of time that equipment is Available and able to perform those activities.
- **Quality –** the effectiveness of the operation to produce units that meet production quality specifications during the period of time that equipment is performing production activity.

"OEE is the most effective measure for driving plant improvement. It continuously focuses the plant on the concept of 0-waste". (Robinson and Ginder 1995 p. 149) "Unless careful monitoring occurs, the reduced capacity goes unnoticed or is accepted as normal. In production, this translates into slower operation, lower capacities, and increased labor costs." (Wireman 1991 p. 21) The JIPM definition for Overall Equipment Effectiveness is the classic definition of OEE and has been used throughout many industries. The JIPM definition of OEE is illustrated in Figure 29. (Nakajima 1984)

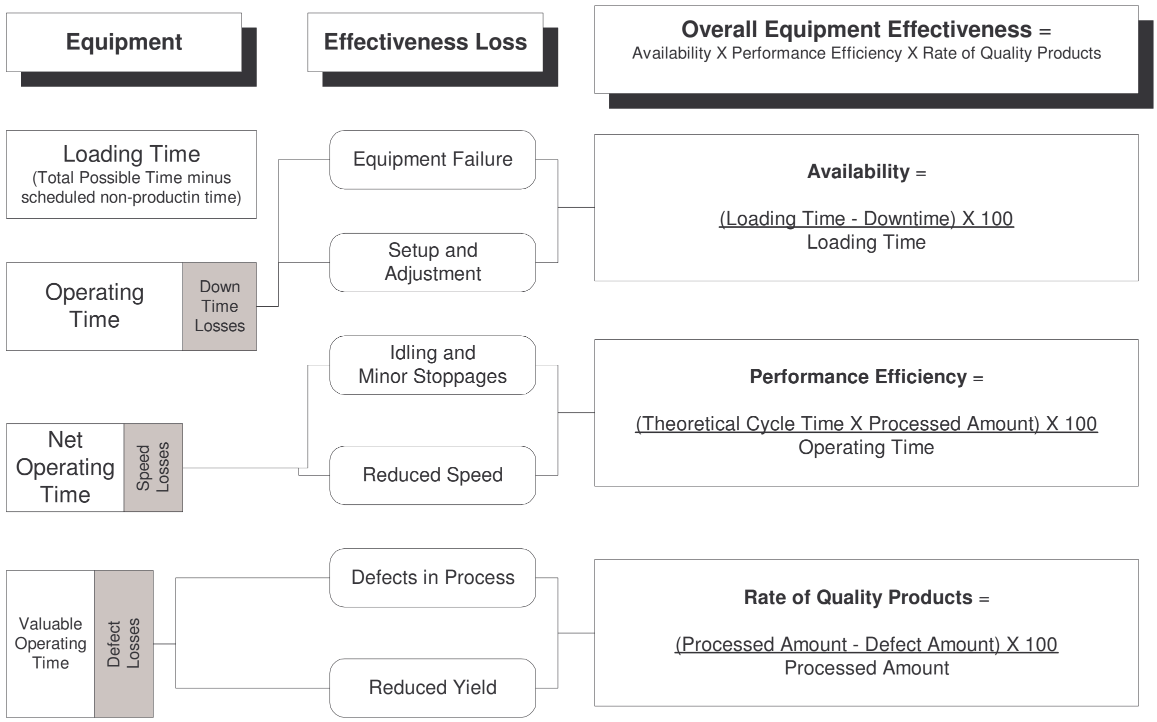

Figure 29 - Overall Equipment Effectiveness Calculation and Losses (Nakajima Method)

Note that in this OEE calculation, the scheduled non-production time[29] is removed from the denominator for the Availability calculation. This, in effect, removes these scheduled non-production losses from the OEE calculation.

With its high capital investment in production equipment necessitating a focus on equipment productivity, the semiconductor industry has created an alternative productivity calculation known as Overall Equipment Efficiency. (SEMI 2000) This calculation differs from the JIPM OEE calculation in that; 1) OEE is based on total potential production hours (168 hrs per week), and 2) the elements of the calculation

[29] In the JIPM OEE calculation scheduled non-production time includes unscheduled shifts or days, periods of scheduled maintenance (PMs), scheduled equipment setups and process changeovers, and scheduled operator non-availability (breaks, meetings, training, etc).

are stated in terms of time (rather than units) to measure efficiency rather than effectiveness. The SEMI OEE calculation, as illustrated in Figure 30, is based on standard semiconductor industry accepted equipment states.[30] (SEMI 2001)

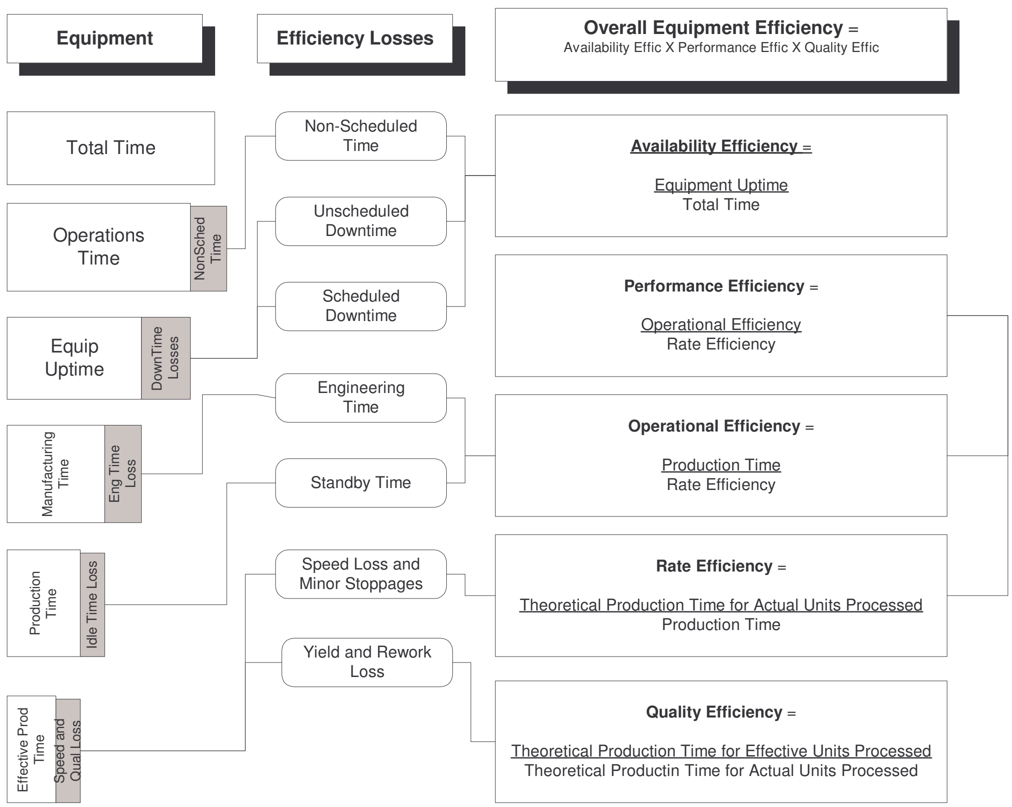

Figure 30 - Overall Equipment Efficiency Calculation and Losses (SEMI Method)

When only the value of OEE is required[31], the OEE calculation can be simplified to

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[30] SEMI E10 defines six major equipment states (Non-Scheduled Time, Productive Time, Idle Time, Scheduled Downtime, Unscheduled Downtime, and Engineering Time). Equipment can be in one and only one of these states at any point in time. SEMI E10 allows for further classification of equipment state through user-defined substates that map the six major states. SEMI (2001). SEMI E10 Standard for Definition and Measurement of Equipment Reliability, Availability, and Maintainability (RAM). San Jose, CA, Semiconductor Equipment and Materials International.

OEE = (Good Units Produced) ÷ (Potential Units Produced) [for the time period]

Where

(Potential Units Produced) = (Total Time) × (Potential Units per Hour) [for the time period]

And

(Potential Units per Hour) = the number of units that would be produced with no equipment effectiveness loss present.

While OEE presents a high level, comprehensive measure of equipment effectiveness (efficiency) and productivity, additional metrics are used to fully analyze and understand equipment performance.[32] (Leflar 2001)

- Mean Time Between Failure (MTBF).
- Mean Time to Repair (MTTR).
- Production Defect Rate.
- Number of Machine Failures (Failure Rate).
- Equipment Availability.
- Number of Minor Stoppages.
- Production Moves or WIP Turns.
- Production Rate.
- Equipment Setup Time.

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[31] For instance, the simplified OEE calculation might be used during the creation of OEE trend charts, when additional information on loss modes is not required.
[32] Equipment performance and productivity measurements will be discussed in further detail in subsequent papers on Reliability Engineering, Reliability Centered Maintenance (RCM), and Equipment Productivity Measurement.

- Production Cycle Time.
- PM Time versus Repair Time (Scheduled DT vs. Unscheduled DT).
- Equipment C_{pk}.
- Number of Equipment Improvements Completed.

6.3 Team-based Improvement Activity (Small Group Activity – SGA)

TPM activity is executed by teams known as small group activity (SGA). TPM succeeds not because of its system or engineering techniques but because of its attention to the management of human factors. (Labib 1999) "A small group is any cross-functional work team charged with working together to improve plant performance by solving problems and managing specific plant areas, machines, or processes." (Robinson and Ginder 1995 p. 54) TPM SGA involves teams that are part of the standing organization. "Although they act autonomously, they do so within the existing organizational framework." (Suzuki 1994 p. 351) Suzuki's TPM structure creates overlapping SGA's with the membership of one level of SGA becoming the leadership of the next level SGA as shown in Figure 31.[33]

This structure drives TPM involvement throughout the organization. "Employee involvement is a necessary part of the TPM process. The goal is to tap into the expertise and creative capabilities of the entire plant or facility through the use of small group activities." (Robinson and Ginder 1995 p. 3)

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[33] Although not shown in this simple diagram, there may be more than one SGA at any level of the organization. Operators may also become leaders additional teams at their level of the hierarchy.

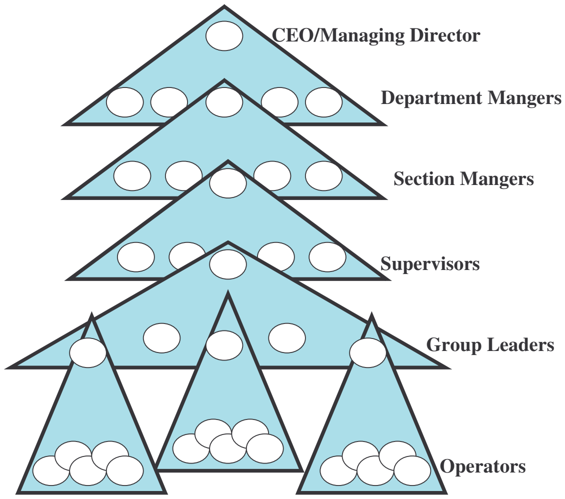

Figure 31- Overlapping Small Group Activity Structure

The roles and membership of SGA teams vary by levels within the organization. "Of course, every level of the organization, such as the company, factory, department, section or team has different functions, missions, authorities, and responsibilities. TPM issues, therefore, differ accordingly." (Tajiri and Gotoh 1992 p. 21) Suzuki provides examples of some common TPM SGA teams. (Suzuki 1994)

- **The TPM Promotions Office** – The Promotions Office is responsible to manage the deployment of the TPM program and plays a central role in ensuring that SGA's evolve actively. It is responsible for keeping the TPM program on track.

- **Senior Management Small Groups** – Consist of department or section managers led by senior management. They are responsible for establishing the basic TPM policy and objectives in line with the corporate and site business goals. The Senior Management SGA sponsors the TPM Promotions Office. In the early stages of TPM implementation, the Senior Management SGA performs the first Manager's Model.

- **Middle Management/Supervisor Small Groups** – Section manager or supervisor SGA's responsible for executing the TPM plan within their departments. The Middle Management SGA's sponsor the shop floor

Autonomous Maintenance teams.[34]

- **<u>Front-line Small Groups</u>** – Cross-functional shop floor teams that execute the TPM plan within their work areas.

It is important to state again that the SGA's do not operate independently, but rather perform TPM activity consistent with the overall TPM plan. "Employee empowerment does not mean that all decisions are made by individual workers or small groups of employees. That would be chaos." (Robinson and Ginder 1995 p. 4) The small groups do not form spontaneously, but rather, are chartered by the higher-level SGA's. The charter for each SGA includes specific boundaries and objectives for their activity. The TPM Promotions Office is responsible to design and deploy the training and education required for SGA success.

Shirose defines three conditions for the success of small groups as shown in Figure 32. (Shirose 1996) Suzuki offers a very similar model for small group success; however, he refers to the three conditions as Motivation, Ability, and Opportunity. (Suzuki 1994)

[34] Both the Senior Management and Middle Management SGA's are responsible for removing barriers to success for the SGA's that they charter and sponsor. "For small groups to succeed, plant management must remove barriers that result from the traditional pyramidal organization." Robinson, C. J. and A. P. Ginder (1995). <u>Implementing TPM: The North American Experience</u>. Portland, OR, Productivity Press.

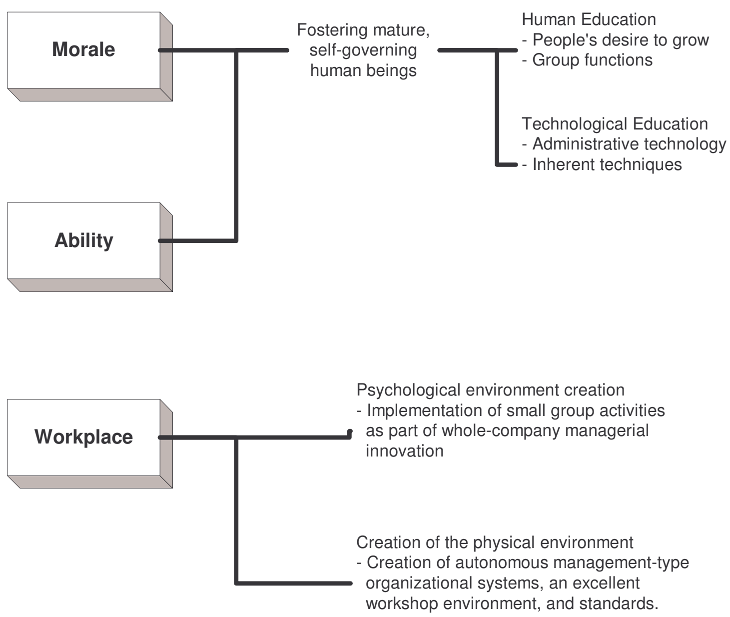

Figure 32 - Conditions for Small Group Success

6.4 Participation Across All Levels of the Operational Hierarchy

"The goal of TPM is to maximize the overall effectiveness of the production system through total participation and respect for the individual." (Suzuki 1994 p. 354) As noted in the previous discussion on SGA's, the top-to-bottom integration of TPM activity is accomplished through interlinking small groups. TPM activities are not voluntary but part of people's daily work. (Suzuki 1994) That includes all levels of the organization from top management to the shop floor workers.

6.4.1 Top-Level Management TPM Responsibilities

"The major issue to successful TPM implementation is manager participation, not just support or commitment, but being fully involved in determining strategy, learning the process by doing, coaching others, and assessing progress." (Ames 2003 p. 2) The top-level managers set the high level TPM policies and objectives, create the TPM Promotion Office, and sponsor the TPM Steering Committee. They must also assign the resources to make TPM successful. That success relies, in part, in assigning top performers to roles within the TPM Promotions Office. "Everyone has a lot on their plate and see TPM as something extra, so committing people to the program is tough…along these lines is the need for a TPM Coordinator. This is a must and it should be one of your best people. This is very hard to commit to in most factories." (Ames 2003 p. 4)

Gardner concurs with the critical role that top-level management plays in TPM success, noting that a key success factor for TPM implementation at National Semiconductor is "steadfast top management support with the Managing Director visibly leading the change. The management model of top management actually rolling up their sleeves and doing a tool restoration over several months reinforces their learning and visibly demonstrates commitment." (Gardner 2003 p. 1)

Top management plays the crucial role in TPM implementation of leading the paradigm shift. "The type of change called for in TPM is especially difficult because in many respects it pervades the fundamental nature of the company's work culture. It reaches through and affects the entire organization." (Society_of_Manufacturing_Engineers 1995 p. 25) Volker and Farrow recognize that during TPM introduction at Texas Instruments top managers must first change their own culture before leading the change throughout the organization. "The real key is changing the culture of the managers. The top manager is going to want TPM to happen, because it makes sense for the business. But the manager cannot just 'want it to happen' and continue in his or her job as before. He or she must also change. The manager has to change his/her actions so that TPM becomes something that is expected, not just something that has to be worked on when there is spare time. To the extent that TPM is seen as an additional task, it will fail. It must be seen as the way business is done." (Volkert and Farrow 2000 p. 3) Tan notes that Fairchild Semiconductor has ensures continued management involvement in TPM by scheduling weekly 'Interactive Walkabouts' that include managers, the TPM Promotions Committee and TPM pillar leaders. (Tan, Hoh et al. 2003)

6.4.2 Middle Management TPM Responsibilities

Middle managers are responsible for establishing the departmental TPM policies based on the top management objectives. "This small group has the role of determining the departmental or sectional principles in accordance with basic TPM principles and major targets of the company, of breaking down major targets, and having frontline small groups set specific targets." (Shirose 1996 p. 545) To effectively guide the shop floor TPM small groups, the middle managers must also actively participate in the TPM activities. (Suzuki 1994)

They are also responsible for managing their resources to effectively support the TPM activities of the shop floor SGA's. "Middle managers, especially those in first-line supervision and the next level, are in a critical position to support TPM. They are in a position, actually, to make or break the effectiveness of TPM. More people report to first-line supervisors in a company than any other level. Thus, the first-line supervisor is really in charge of most of the ingredients of productivity: the people, the assignment of schedules, the assignment of work, directing people, coaching, counseling, seeing that they get the right education and training…First-line supervisors must be committed to achieving the results of TPM, and they must have the opportunity to share their ideas for improving equipment effectiveness in the design of the company's TPM strategy." (Society_of_Manufacturing_Engineers 1995 p. 24)

7. Success Criteria for TPM Implementation

For continuous improvement programs to be successful they must…

1. Continually improve business results at a competitive pace.
2. Focus improvement activity on the vital few problems instead of the trivial many. (Leflar 2001)

When implemented effectively, TPM provides the processes and methods to accomplish this. TPM literature presents many success criteria for TPM implementation. Following is a list TPM implementation, success criteria that appear to be a recurring theme among TPM authors[35].

1. Follow an established TPM implementation process. (Nakajima 1984; Nakajima 1988; Suzuki 1994; Ames 1996; Shirose 1996; Pomorski 1997; Gardner 2000; Leflar 2001; Ames 2003)

   "It wastes time and other resources to try to re-invent TPM. It is important to learn from others who have succeeded at creating a factory

[35] This is not intended to be an all-inclusive list of success criteria by any means. Similarly, cited references present a sampling and do not suggest that these are the only authors presenting these success criteria. This does, however, represent some of the most commonly occurring themes presented in the TPM literature.

with world-class productivity." (Leflar 2001 p. 39)

2. Commit management to the TPM Process. (Nakajima 1988; Nakajima 1989; Suzuki 1994; Horner 1996; Shirose 1996; Pomorski 1997; Bosman 2000; Leflar 2001; Ames 2003; Gardner 2003; Tan, Hoh et al. 2003)

   "There is a clear need for defined, influential leadership of the TPM initiative." (Horner 1996 p. 8)

   "Top Management plays a crucial role in supporting the necessary techniques and providing advice and guidance in altering processes." (Bosman 2000 p. 6)

   "Employees won't change how they work because a TPM consultant – whether from outside the company or the TPM program office manager – wants them to. Employees change only when their own managers want them to and reinforce the changed behavior properly." (Leflar 2001)

   "…the managerial contextual variables, which are under the jurisdiction of plant management, are *more* important to the execution of TPM programs than environmental and organizational variables. Clearly, the use of TPM programs is strongly linked to the management of the plant." (McKone, Schroeder et al. 1999 p. 139)

3. Integrate TPM with other continuous programs.[36] (Lean Manufacturing, Total Quality Management, 6-Sigma, etc)**.** (Willmott 1994; Pomorski 1997; Jackson 1999; Nakajima 2000; Ames 2003; Gardner 2003; Tan, Hoh et al. 2003)

   "To get the most out of TPM, you should integrate your equipment management efforts with TQM and JIT. They work together to produce the greatest improvements in quality, cost, reliability, and lead time." (Jackson 1999 p. 4)

   "Just in Time will not work unless you have highly reliable and effective equipment, where the interface between people and machine is maximized – which is a major objective of TPM." (Willmott 1994 p. 5)

4. Link TPM activity directly to corporate business goals and objectives. (Nakajima 1984; Nakajima 1988; Suzuki 1994; Horner 1996; Shirose 1996; Pomorski 1997; Jackson 1999)

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[36] Additional detail on the integration of TPM with continuous improvement programs, particularly Lean Manufacturing, will be included in a subsequent paper within this TPM learning module.

”Link TPM directly to important business objectives, otherwise you’ll never build the support necessary for success.” (Jackson 1999 p. 4)

5. Document learning gained during TPM activity.[37] (Jackson 1999; Leflar 1999; Leflar 2000; Leflar 2001)

   ”Many people get swept up in the excitement of learning. But someone’s got to take notes so that you can leverage great ideas and avoid making the same mistakes twice…Organizational learning is an imperative for success…and organizational learning depends on capturing the learning that takes place in individual areas so that they can be deployed elsewhere. This is especially true when you’re doing TPM, because TPM relies on good documentation to break the vicious cycle of commissioning equipment that’s difficult to operate and maintain and that regularly breaks down and produces defects.” (Jackson 1999 p. 5)

6. Stay the course! TPM implementation will not always proceed smoothly, patience and determination is required. (Nakajima 1984; Nakajima 1988; Suzuki 1994; Shirose 1996; SEMATECH-International 1998; Mika 1999; Gardner 2003; Tan, Hoh et al. 2003; Thomas 2003)

   ”Only steadfast adherence to the … TPM vision has led to success. One guiding principle that has resulted in progress to current levels is, ‘We are going to implement TPM right the first time, even if it takes a little longer’…Occasional course corrections have been made to allow for production ramps, overly aggressive TPM implementation plans and unforeseen events. Short cuts or unrealistic timelines result in failure and restarts. The key is to learn from mistakes and make subsequent efforts better.” (Gardner 2000 p. 2)

8. Barriers and Obstacles to Successful TPM Implementation

Elliot presents eleven general barriers to achieving manufacturing excellence that might well summarize many of the barriers to successful TPM implementation. (Elliott 2001) As expected, many of the barriers align closely with the success factors

[37] See Pomorski, T. (2002). Learning Organizations: Concepts, Practices, and Literature Review. Cincinnati, OH, The Union Institute and University. for a detailed discussion of organizational learning and Learning Organizations.

for successful TPM implementation; that is to say, successful implementers leverage the success factors to overcome the obstacles and barriers.

1. Underestimating the task.

   ”Excellence requires a total commitment to process capability, variation reduction, and creation of a benchmark employee knowledge base.” (Elliott 2001 p. 7)

2. Lack of management consensus.
3. Underestimating the importance of knowledge.

   ”Often, managers believe that the only missing performance ingredient is effort.” (Elliott 2001 p. 8) Documenting and proliferating knowledge and learning was discussed in the previous section on success criteria for TPM implementation.

4. Complexity strangles performance.

   Complexity “is the single greatest deterrent to performance excellence”. (Elliott 2001 p. 8) Following a proven standard implementation strategy and process reduces the complexity and the unknown.

5. Inconsistent and unclear expectations.
   a. Objectives that create organizational conflicts.
   b. The use of generalized or concept objectives without specific, measurable, activity-driven performance goals.
6. The challenge of passion.

   ”Excellence is the most difficult of all business or personal objectives to define and achieve. It requires an uncompromising passion to excel.” (Elliott 2001 p. 8) Note the consistency with Nakajima’s passion for zero-fail/zero-quality loss/zero-accident. As Hall states bluntly, "TPM is driven by a few passionate *maniacs on a mission*!" (Hall 2003)

7. Staffs that take charge. (Staff objectives not consistent and aligned with organizational performance goals.)
8. Neglecting the basics.

   ”Without a focused organizational commitment to the basics of variation reduction, service, cost, and safety, there is no foundation on which to build a successful strategic plan.” (Elliott 2001 p. 8)

9. Resistance to daily discipline.
10. Limited involvement experience. (Total organizational commitment to address shortfalls in individual and organizational knowledge and improvement process experience.)
11. Too much focus on output measures rather than the quality of the process input.

Like success criteria, TPM literature identifies numerous barriers to successful implementation, many of which have been identified within Elliot's barriers to manufacturing excellence. Some additional barriers to TPM implementation that must be addressed include the following.[38]

- Implementing to a rigid schedule regardless of results. (Ames 2003; Gardner 2003; Tan, Hoh et al. 2003; Thomas 2003)

  This is really two-faced barrier. The first concern is establishing unrealistic implementation schedules, whether due to ignorance or lack of experience. Management pressure for quick wins versus a long-term commitment to improvement is also noted. "Generally speaking, most managers tend to be very impatient". (Tan, Hoh et al. 2003 p. 3) The second concern is not altering the schedule once it is obviously not appropriate.

- Deploying insufficient resources for successful implementation. (Ames 2003; Gardner 2003; Thomas 2003)

  "Traditional JIPM [TPM] processes consume significant resources at a time when corporations are trying to run as lean as possible…many companies…are trying to understand where short-cuts can be taken to gain 'quick wins' and utilize fewer resources. Some of these same companies also point to the underlying principles of Theory of Constraints and have only implemented TPM concepts on constraint tool sets." (Thomas 2003 p. 5)

  Ames considers resources, "…taking the time and providing the resources [people]", the most critical barrier to TPM implementation. (Ames 2003 p. 4) Until TPM becomes a way of doing business, implementation is an additional burden on the change implementers.

[38] Again, this is not an all-inclusive list of barriers to TPM implementation, but does represent themes that are presented in the TPM literature.

Gardner notes that it is a requirement of management to "consciously load level the organization so that TPM does not overburden your top people." (Gardner 2003 p. 2)

Shingo, on the other hand, presents an important reminder when identifying the lack of resources to be a reason for implementation failure when he says that *lack of resources may be a lack or resourcefulness*. (Shingo 1982)

- Resistance to change.

  Resistance to change takes a number of forms.

  - Reluctance of individuals to change roles. (Robinson and Ginder 1995; Riis, Luxhoj et al. 1997; Cooke 2000)
  - Inability to create dissatisfaction with the present situation (reason to change). (Maggard and Rhyne 1992; Steinbacher and Steinbacher 1993; Ireland and Dale 2001)

    "The most difficult aspect of implementing TPM is to get every one in the organization to recognize the need for change and to commit themselves." (Steinbacher and Steinbacher 1993 p. 47)

  - Inability to change organizational roles and culture. (Patterson and Fredendall 1995; Lawrence 1999; Cooke 2000; Thomas 2003)

  The organization's ability to understand the restraining and driving forces[39] related to this resistance to change is critical to overcoming the barrier. (Bamber, Sharp et al. 1999)

- Recognizing the benefits of TPM implementation. (Sekine and Arai 1992; Robinson and Ginder 1995; Cooke 2000; Tan, Hoh et al. 2003)

  For TPM to be successful, "the improvement process must be recognized as benefiting both the company and the worker." (Robinson and Ginder 1995 p. xvi)

  "A common reason for the operator's resistance to the idea of TPM is its perceived unfairness and one-sidedness. For the majority of production people interviewed, having a role in the first line maintenance means doing

[39] For a detailed discussion of restraining and driving forces (field-force analysis) see Pomorski, T. (2002). Change Management for Organizational Continuous Improvement: Literature Review. Cincinnati, OH, The Union Institute and University.

more work but without any more money.” (Cooke 2000 p. 1013)

- TPM presented as ‘the program of the month’.

  ”TPM is a long-term strategic initiative rather than a short-term tactical fix. It will fail if a ‘program of the month’ mentality exists.” (Robinson and Ginder 1995 p. 7)

  ”For the most part, participants talked about TPM as a long-term process, not a quick fix for today’s problems. This seems to be an important attitude to hold, because results are not immediate or even quick. To see the full benefits of TPM, it appears that organizations need to make a continued commitment to the possibilities and philosophy espoused by TPM methodology.”[40] (Horner 1996 p. 9)

- TPM implementation is dependent on continued engagement of one or too few specific individuals.

  ”Winning requires an institutionalized management proof process that is sustainable despite changes in leadership, strategy, and business conditions…” (Elliott 2001 p. 7)

- Implementing a ‘look at us’ TPM campaign. (Superficial implementation to impress auditors or customers without true commitment to the TPM goals of zero-failures, zero-quality losses, zero-accidents.) (Sekine and Arai 1992)

- Lack of analysis capability. (OEE and equipment performance) (Patterson and Fredendall 1995)

9. Future Directions for TPM Implementation

As a continuous improvement methodology, the TPM process itself undergoes continuous improvement. Thomas observes that “in highly technical, rapidly changing environments, traditional TPM methodologies will have to be adapted to

[40] Other TPM researchers concur that TPM is a long-term process, but would argue that some immediate results and quick fixes are possible, and are in fact commonly achieved.

provide earlier returns if it is to become a viable means for improvement." (Thomas 2003)

9.1 Integrated Continuous Improvement Activity[41]

Numerous authors have noted that TPM and Lean Manufacturing[42] are highly complimentary continuous improvement processes. TPM focuses on the optimization of equipment and process productivity (OEE and OFE) while Lean Manufacturing addresses the elimination of waste (labor, time, cost, inventory, etc) while establishing customer-driven (pull), Just-in-Time (JIT) production. As Ames says, "Lean starts with the machine…In automated manufacturing processes, the equipment is the heart and soul of the operation and TPM is the equipment-focused continuous improvement process to maintain the health and well-being of the equipment" (Ames 2003) Lean Manufacturing (as well as other manufacturing continuous improvement programs) rely on stable, reliable equipment with no variation in processing. "Just-in-Time will not work *unless* you have highly reliable and effective equipment, where the interface between people and machine is maximized…" (Willmott 1994 p. 5) Similarly, Shirose observes TPM enables JIT by eliminating sporadic failures and minor stoppages, eliminating defects in processing, and improving the efficiency of maintenance activities. (Shirose 1996) TPM and Lean Manufacturing, in fact, share common implementation tools including visual

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[41] A subsequent paper in this TPM learning module will discuss the integration of TPM with other continuous improvement methodologies in further detail.
[42] See Pomorski, T. (2002). Lean Manufacturing: Concepts, History, and Literature Review. Cincinnati, OH, The Union Institute and University. for an overview of Lean Manufacturing practices.

controls and the 5S process. Productivity, Inc. states simply “Lean and TPM cannot be separated”. (Productivity 2000)

Other authors have similarly observed that TPM and Reliability Centered Maintenance (RCM) are highly complimentary. (Ben-Daya 2000; Hoshino 2000; Waeyenbergh and Pintelon 2002) RCM provides effective tools to identify equipment faults (TPM Focused Improvement pillar) and to develop and schedule planned maintenance activities (TPM Planned Maintenance pillar). TPM is also the foundation and enabling element that ensures reliable, variation-free equipment performance for Total Quality Management (TQM) (Nakajima 1988; Society_of_Manufacturing_Engineers 1995; McKone, Schroeder et al. 1999), ISO deployment (Inoue 1998; Koike 1998; Ohno 1998; Takahasi 1998), 6-Sigma (Gardner 2003; Tan, Hoh et al. 2003; Thomas 2003; Thomas 2003) and Learning Organizations (Senge 1990; Japan_Institute_of_Plant_Maintenance 1997).

The Society of Manufacturing Engineers views TPM as an empowering process that serves as the foundation of productivity improvement processes as illustrated in Figure 33.

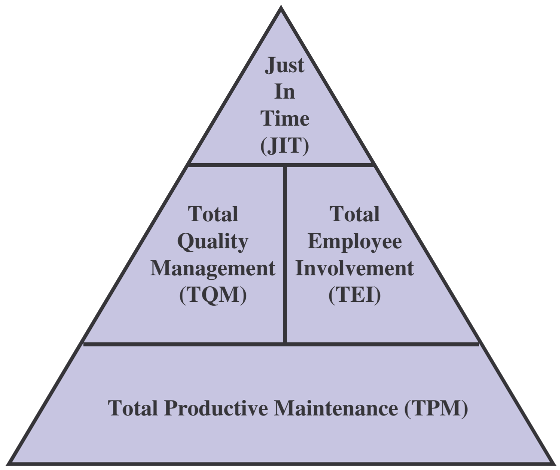

Figure 33 - The Productivity Pyramid

Discussion of the integration of TPM with 6-Sigma is emerging currently, and developments bear watching.

9.2 Expanded scope of TPM objectives – Overall Factory Efficiency

Early TPM implementation was known for its equipment focus. Building from Preventive Maintenance (PM) methodologies, this was a logical first-step for TPM early adaptors. In complex manufacturing environments equipment performance and reliability is a key, if not primary, contributing factor to overall manufacturing performance. As TPM practices, processes, and methodologies mature, the scope of TPM objectives expands beyond this equipment focus and seeks out improvement opportunities throughout enterprise operations. For instance, mature TPM implementations deploy a pillar focused specifically for Administrative

TPM. Nakajima refers to deploying TPM to improve the production system rather than simply equipment performance. (Nakajima 1984; Nakajima 1988) Overall Equipment Effectiveness (OEE) has been noted as a primary measurement of TPM. Overall Factory Efficiency (OFE) is emerging as an advanced measure of the production system efficiency.[43]

"The effectiveness of a plant's production depends on the effectiveness with which it uses equipment, materials, people, and methods. Raising production effectiveness in process industries, therefore, starts with the vital issues of maximizing overall plant effectiveness (equipment), raw materials and fuel efficiency (materials), work efficiency (people), and management efficiency (methods). Examine the inputs to the production process (equipment, materials, people, methods) and identify and eliminate the losses associated with each to maximize the outputs (productivity, quality, cost, delivery, safety, environmental, and morale). (Suzuki 1994 p. 21)

9.3 Automation in TPM Implementation[44]

Factory automation is emerging as a critical element TPM implementation. According to Thomas, automation and information technology are an enabling tools for TPM that can lead to improvements in virtually any TPM pillar. As a specific

[43] Within the semiconductor industry, effective management of Overall Factory Efficiency is noted as a critical success factor for 300mm semiconductor fabrication. Semiconductor_Industry_Association (2002). International Technology Roadmap for Semiconductors: 2002 Update. San Jose CA, Semiconductor Industry Association. A standard methodology for measuring Overall Factory Efficiency in semiconductor operations has been developed. SEMI (2003). SEMI E124: Provisional Guide for Definition and Calculation of Overall Factory Efficiency (OFE) and Other Associated Factory-Level Productivity Metrics. San Jose, SEMI.

[44] A detailed discussion of the role of automation in manufacturing productivity will be included in a subsequent paper on Automation Engineering.

example, he notes, "In the semiconductor industry, where most processing and metrology equipment is already highly automated, further improvements in automation are often the most likely means for improving rate efficiency". (Thomas 2003)

Authors note the following specific applications of automation to support effective TPM programs.

- Data Collection and Analysis.

  As the complexity of manufacturing operations increases, performance data collection and analysis becomes more difficult. Hino, for instance, observed that manual data gathering was becoming ineffective at Sankyou Seiki Siesakujyo. "A continuation of this situation would have led to a decline in the improvement awareness and improvement capabilities of operators, impeding equipment improvements." (Hino 1998 p. 5)

  Computers are helpful in establishing an information base and for organizing that information in an easy to use, retrievable, electronic filing cabinet." (Robinson and Ginder 1995 p. 69) Automation enhances the accuracy and timeliness of data collection, analysis, and reporting. (Ames 2003)

  A number of automation components[45] are of specific interest to data collection and analysis in TPM implementation.[46]

  - Computerized Maintenance Management System (CMMS)[47]: Typical CMMS functionality includes the following.
    - Equipment state (condition) tracking.
    - Maintenance task management. (standard work procedures)
    - Preventive Maintenance scheduling and management.
    - Equipment performance analysis and reporting.
    - Parts tracking and management.
  - Manufacturing Execution System (MES): The core of factory automation, MES systems include the following functionality.

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[45] Basic functionality of automation components is identified. In many cases, one or more specific automation products or tools may execute these capabilities.
[46] Detailed functionality and integration of automation components will be discussed in a subsequent paper on Automation Engineering.
[47] An emerging term for advanced CMMS systems is Enterprise Asset Management (EAM).

        - Work-in-Progress (WIP) tracking and management.
        - Process flow mapping and management.
        - Process quality (scrap and rework) management.
        - Production performance analysis and reporting.
    - Statistical Process Control (SPC)
        - Real-time (or near real-time) statistical analysis of product or equipment performance (quality) parameters.
        - Alarm and exception notification and management.
        - SPC analysis and reporting.
    - Equipment Automation
        - Monitor and manage equipment operation.
        - Equipment alarm notification and management.
        - Equipment interface to other automation components.
    - Fault Detection and Classification (FDC)
        - Identify and capture equipment faults, errors, or variance.
        - Classify failure mechanisms for analysis.
        - FDC reporting.

- Process Control and Management.

  Automation provides control and management capability (elimination of variance) in advanced manufacturing operations. CMMS, MES, SPC and Equipment Automation were discussed were already presented as tools data collection and analysis. These automation components also provide control and management capabilities.

  Additional automation components to support process control and management include the following.

    - Advanced Process Control (APC)/Automated Run-to-Run Control (ARRC)
        - Monitor and detect variance in product quality or equipment performance.
        - Execute real-time closed-loop correction to eliminate processing variation.
    - Work Management and Dispatching
        - Rules-based work dispatching.
        - Production and maintenance task management based on real-time automated decision making.
    - Alarm and Exception Management

- Automated identification of equipment and process variation[48].
- Deploy standard response activity to contain and eliminate process and equipment variation.

- The 'Visual Factory'.

  The Visual Factory is an extension of TPM visual controls in an automated environment. "The term 'Visual Factory' encompasses a system of data repositories, query engines, and web applications that together derive, format, and deliver targeted information to various functional groups." (Juhl 2003 p. 1) The goal of the Visual Factory is to put Key Performance Indicators (KPI's) in the hands of users (managers, engineers, supervisors, operators) in real-time, easy-to-access formats. A 'Data Dashboard' that displays user-specific manufacturing performance information typically supports the Visual Factory. The Data Dashboard is highly integrated with the other automation components to collect and display information critical to the KPI's.

It is important to note that factory automation is not the 'magic bullet' for successful TPM implementation. It is certainly an important tool, but not the entire solution and cannot be viewed as the quick fix that allows an operation to avoid the hard work of establishing an effective continuous improvement program. (Upton 1995) Sekine observes that rushing to full automation prematurely may, in fact, hamper the TPM program. (Sekine and Arai 1992) '*Appropriateness to the task* ' is the most important consideration when deploying automation to support TPM. "…The system is not the solution…the effective use of the system is the solution." (Robinson and Ginder 1995 p. 69) Like all other tools, the benefit of automation must exceed the cost and the results must be aligned with the TPM goals and objectives. "Automation can help or hurt TPM implementation. If it provides

[48] Identification of the alarm condition is frequently detected by another automation component such as SPC, Equipment Automation, MES, or CMMS.

excellent process control, information, and machine operation it is an enabler. If it impedes the same, it is a barrier." (Gardner 2003)

One topic that has not received significant investigation in the TPM literature is the use of TPM methodology towards the continuous improvement of automation hardware and application performance. Highly automated manufacturing operations are increasingly dependent on factory automation; many, in fact, cannot function without automation support. This is an area that merits further research.

10. Conclusion

As defined in this paper, *Total Productive Manufacturing (TPM) is a structured equipment-centric continuous improvement process that strives to optimize production effectiveness by identifying and eliminating equipment and production efficiency losses throughout the production system life cycle through active team-based participation of employees across all levels of the operational hierarchy.* Although TPM is historically equipment-focused, effective implementation offers a continuous improvement methodology to increase overall manufacturing productivity. TPM methodology provides enterprises with the tools required to explore, increase, document, and proliferate organizational learning. According to Leflar, "…improved machine performance is the result of improved behaviors from people involved in the machine's life cycle. Improved behavior comes from new learning. Continuous improvement is born of continuous learning." (Leflar 2000 p. 7) Research and case studies indicate that TPM implementation can have significant positive impact on manufacturing performance. Wang and Lee found that TPM is equally effective in small plants and large plants as well as in different countries and cultures. (Wang and Lee 2001)

Leflar provides a succinct overview of the basic principles of TPM. (Leflar 2001 p. 5)

1. Minor defects are the root cause of most equipment failures and must be completely eliminated from all equipment. Equipment with minor defects will always find new ways to fail and improvement activity will never be able to keep pace with the failure rates of the machine.
2. Properly planned maintenance routines can prevent almost all sporadic equipment failure. Scheduled maintenance is the foundation for all TPM activity.
3. Cross-departmental teams can advance equipment performance with much greater ease than efforts made by a single department working alone. This is especially true for chronic failures and quality problems.
4. Continuous learning is the heart of continuous machine improvement.
5. Machines with effective preventive maintenance programs make more product than machines that are only repaired when they break down.
6. Effective preventive maintenance plans require less technician time than the time required to repair poorly maintained machines.

Successful implementation of TPM is not a simple task for organizations and many fail to achieve their TPM goals or abandon TPM implementation altogether. This paper identifies many roadblocks to effective implementation as well as success criteria to overcome those roadblocks. TPM success requires strong and active support from management, clear organizational goals and objectives for TPM implementation, disciplined execution of the TPM methodology, an unwavering focus on elimination of equipment/process breakdown and quality loss, organization willingness and ability to learn and change, and committed focus on long-term objectives. "TPM aims to create corporate environments able to respond positively to the changing business climate, technological advances, equipment sophistication, and management innovation." (Suzuki 1994 p. 261)

TPM is itself an adaptive process, changing to support increasingly complex environments. TPM is an enabling methodology when integrated with other continuous improvement programs such as Lean Manufacturing, Total Quality Management, or 6-Sigma. Although further research and experience is warranted, TPM provides opportunity as an effective tool to improve the performance of factory automation. TPM Maintenance Prevention activity pushes reliability and performance improvement opportunity from the factory floor to equipment and process design and construction. "I think TPM is needed more than ever before. As equipment becomes more complex and expensive we have to find ways to make it more productive." (Ames 2003)

11. Table of Figures

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