A Methodology for Implementing Total Productive Maintenance in the Commercial Aircraft Industry

by

Eugene C. Hamacher

B.S. Electronics Engineering Technology, DeVry Institute of Technology (1987)

Submitted to the Sloan School of Management and
the Department of Electrical Engineering and Computer Science
in Partial Fulfillment of the Requirements for the Degrees of

Master of Science in Management and
Master of Science in Electrical Engineering and Computer Science

in conjunction with the Leaders for Manufacturing Program
at the
Massachusetts Institute of Technology
May 1996

Signature of Author ________________________________
MIT Sloan School of Management
Department of Electrical Engineering and Computer Science

Certified by ________________________________
Professor Janice A. Klein
MIT Sloan School of Management, Thesis Advisor

Certified by ________________________________
Professor Eugene E. Covert
MIT Department of Aeronautics and Astronautics, Thesis Advisor
Department of Electrical Engineering and Computer Science Approved Reader

Accepted by ________________________________
Jeffrey A. Barks
Associate Dean, MIT Sloan School of Management

Accepted by ________________________________
Frederic R. Morgenthaler
Chair of Departmental Graduate Committee

A Methodology for Implementing Total Productive Maintenance in the Commercial Aircraft Industry

by

Eugene C. Hamacher

Submitted to the Sloan School of Management and
the Department of Electrical Engineering and Computer Science
in Partial Fulfillment of the Requirements for the Degrees of
Master of Science in Management
and
Master of Science in Electrical Engineering and Computer Science
May 1996

Abstract

The Boeing Company is currently undertaking a metamorphosis in order to become more competitive in the commercial airplane market. A large component of this change is an effort to improve manufacturing capabilities, while reducing overall production costs. To accomplish these goals, Boeing must improve both the quality of their products and the reliability of their production equipment. The implementation of Total Productive Maintenance (TPM), applied in the proper environment, can provide Boeing with an effective set of processes to drastically improve their manufacturing effectiveness through more reliable production equipment. However, Boeing currently does not have a reliable, repeatable methodology for implementing TPM. The intent of this research is to establish an effective approach for implementing TPM.

Many new manufacturing processes are being introduced to improve Boeing's manufacturing capabilities. One of these processes is based on the concept of using 'self-locating' parts that are assembled via coordinated holes, which allows the elimination of a significant number of assembly fixtures and replace them with a single, flexible Computer-Numerically Controlled (CNC) work cell. This assembly method improves the flexibility of the manufacturing system and reduces hardware variability associated with tooling fixtures. Since this CNC equipment determines the final product configuration, any variation in this equipment's performance directly affects the variation in the production parts. This direct linkage requires an increased emphasis on equipment performance. By implementing TPM in these situations, the manufacturing costs associated with variability in both product quality and production schedules can be reduced.

This thesis contains the results of a six month internship at the Boeing Company in the 757 Fuselage Assembly Business Unit. The following conclusions are provided:

- These new aircraft assembly methods increase the dependence on equipment performance
- TPM reduces the manufacturing costs associated with equipment performance
- The existing TPM activities within the Boeing Commercial Airplane Group provide a rich source of TPM implementation lessons learned which can be applied to other facilities

Thesis Supervisors: Professor Eugene E. Covert, Department of Aeronautics and Astronautics
Professor Janice A. Klein, Sloan School of Management

Acknowledgments

The author gratefully acknowledges the support and resources made available to him through the Leaders for Manufacturing Program and the Boeing Company. I specifically want to thank Bettina VonAkerman for going "above and beyond the call of duty". She always gave the LFM students more than we deserved, and never got enough credit for her hard work.

I would like to thank my advisors, professors Eugene Covert and Jan Klein for their insight and suggestions. They allowed me to explore my capabilities and then helped me to focus my findings.

I would like to thank the many employees at the Boeing Company who took the time to share their ideas and insight with me. In particular, I would like to thank Lindsay Anderson, Tony Micale, Pauline Marshall, Steve Lorang, Steve Dightman, Celia Shepherd, Steve McConnell, and Rod Christensen for providing me with the majority of the knowledge that I acquired during this internship, and for helping me to keep all of this information organized.

I would also like to thank my family and friends who provided me with support and words of encouragement through the entire Leaders for Manufacturing program, particularly my parents Ed and Shirley Hamacher. I truly enjoyed making new friends in the Leaders for Manufacturing Program and rediscovering old friends at the Boeing Company.

Most of all, I would like to thank my wife, Joanne, for her patience and dedication, and for helping me keep my priorities straight during the past two years. I could never have persevered this challenging experience without her support, sense of humor, and unquestioning love.

Table of Contents

List of Figures

1. Introduction

The Boeing Commercial Airplane Group (BCAG) is currently making a series of changes to become more competitive in the commercial aircraft market. A large component of this change is an effort to improve manufacturing capabilities, while reducing overall production costs, and improving responsiveness to customer demands. To accomplish these goals, BCAG must improve the quality of their products and the reliability of their production equipment and also reduce product cycle times. In many facilities throughout BCAG, the implementation of Total Productive Maintenance (TPM) can provide an effective set of processes to improve their manufacturing effectiveness through more reliable production equipment. However, BCAG currently does not have a reliable, repeatable methodology for implementing TPM. The intent of this research is to establish an effective approach for implementing TPM.

The results of this research include the following:

- The linkage between hardware variability, production delays, and production equipment management will be determined
- A methodology for implementing new manufacturing processes, such as TPM, will be documented
- A comprehensive implementation plan for deploying TPM concepts will be described
- An evaluation of the existing TPM activities within BCAG will be provided

1.1 Commercial Airplane Market

The environment in the commercial aircraft industry has seen significant changes in the last six years, primarily driven by the success and failure of the world's airlines. The last six years have been marked by enormous declines in the profitability of the airlines, followed by a small recovery. One of the most graphic descriptions of this decline in profitability is the fact that "the combined profits of the world's airlines between 1990 and 1994 was not enough to buy a single Boeing 737".[1] This decline in airline profitability ultimately results in fewer and fewer airplanes being ordered from the manufacturers.

Although the airplane manufacturing companies that compete for this market have not significantly changed during this time, the size of the overall market has seen dramatic changes. The following chart shows both the number of airplanes sold per year and the revenue generated from the sales.. This chart depicts just how significant these changes have been from year to year.[2]

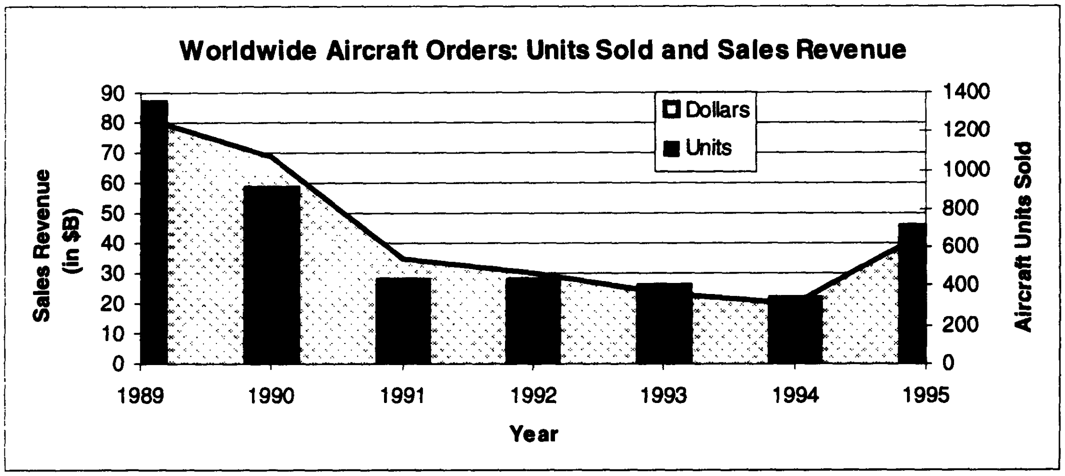

Figure 1: Total Aircraft Sales by Units and Revenue

One of the results of this shrinking commercial jet aircraft market has been increased competition among the aircraft manufacturing companies. With a smaller pie being divided up among the same number of manufacturers, the pressure to win one of the few new airplane orders is extremely high. During the competition for orders during 1993 and 1994 it was not uncommon for the press to report rumors that the winning company had sold their airplanes at, or below cost. The most noticeable fall-out of this reduction in aircraft orders is the impact on the workforce at the manufacturing companies. "Between the years of 1990 and 1995 an estimated 30,000 jobs were eliminated at Boeing Commercial Airplane Group".[3]

---

[1] Griffin, Sean, "Paris Air Show", *The News Tribune*, June 14, 1995.

[2] The Boeing Company, Sales and Marketing Information.

[3] Cole, Jeff, "Boeing Commercial-Jet Unit", *The Wall Street Journal*, February 9, 1996.

Fortunately, by the end of 1994 many of the world's airlines saw a return to profitability, which created an upswing in the number of aircraft orders placed during 1995. However, many of the airlines were still demanding the competitive pricing that was common during the times of sparse aircraft orders. The airplane manufacturers are now faced with the challenge of increasing production rates, while keeping their prices low. The reward for achieving this will likely be an increase in market share for the successful companies. The following graph of recent trends in aircraft orders, shows this reported upswing in aircraft orders, as well as how the orders are being shared among the manufacturers.[4]

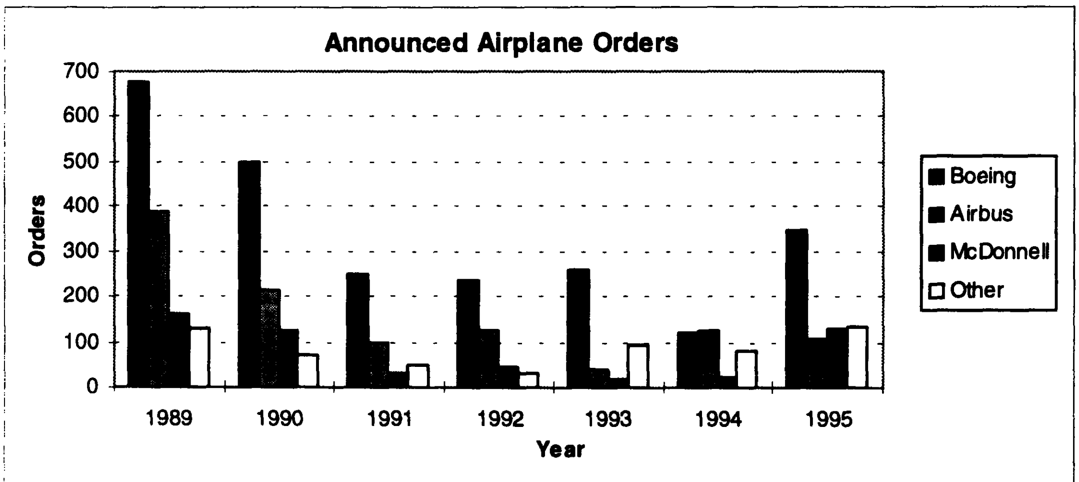

Figure 2: Annual Airplane Orders by Manufacturer

The companies that can remain competitive into the future by controlling their production costs, improving their quality, and reacting efficiently to customer demands may survive to witness tremendous growth in the aircraft industry. Recent estimates of the commercial jet aircraft market show "growth of up to 15,000 airplanes per year, by the year 2014. This growth represents approximately a $1 Trillion per year market".[5]

The manufacturer that will gain the largest portion of this future market will undoubtedly be the one that best satisfies their customers. Delivering a high quality aircraft

[4] The Boeing Company, Sales and Marketing Information.

[5] Sebastian, Pamela, "Business Bulletin", *The Wall Street Journal*, June 22, 1995.

on time, and at a reasonable price, will depend heavily on the manufacturing capability of these manufacturers. Utilizing reliable manufacturing processes that maximize equipment effectiveness, minimize production delays, and control hardware variability will become 'competitive requirements' rather than 'competitive advantages'. The flexibility of the production process to quickly adjust to changes in the marketplace will also become more important as product diversity increases.

1.2 Boeing's Response to Market Changes

One of the initial steps taken by Boeing management to address the changes in their competitive environment was to learn what other manufacturing companies had done when faced with similar situations. Many of Boeing's senior executives spent over a year going on 'study missions' to learn how world class companies were addressing these challenges. This significant benchmarking exercise resulted in a new awareness of Boeing's competitive position, and on how to improve it. These senior executives felt it was imperative to inform the rest of the company of their findings.

Based on the findings from the senior executives study missions, BCAG began implementing a set of concepts known as World Class Competitiveness (WCC). The implementation has included training virtually all BCAG employees in two and four day classes on "Managing for World Class Competitiveness". This training alone required nearly two years to complete and implementation efforts are still continuing. The WCC training was intended to give all employees a 'common language' that would allow for more effective communication in the work place and to create a heightened sense of urgency for employees to make drastic improvements in their processes. The WCC training also provides a significant number of problem solving tools for employees to utilize when making these improvements.

According to BCAG's WCC literature, a production system contains the following four basic elements: Safety, Housekeeping, Education, and Total Productive Maintenance (TPM). BCAG has put forth a great deal of effort toward improving the safety of the workplace as well as implementing a 5 S program (Sorting, Simplifying, Sweeping, Standardizing, and Self-Discipline) to address the housekeeping issue. BCAG also recently created a 'Center for Leadership and Learning' which will provide additional education to their employees. Unfortunately the fourth basic, TPM, has not seen a comparable level of focused effort. TPM includes the transfer of many maintenance tasks from the maintenance technicians to the equipment operators, as well as a proactive approach for equipment repair and replacement. Further, the integration of the four "basic elements" has not received extensive attention.

Recently, BCAG has been making changes in their organizational structure to improve communication and product - process alignment. Instead of the typical 'functional silos', organizations have been changed into smaller, cross functional responsibility centers (RC's) and manufacturing business units (MBU's). The difference between these is that the RC has engineering design authority resident in the organization, where the MBU utilizes liaison engineers that report back to a centralized design organization. Each of these RC's and MBU's represent a co-located team that has responsibility for a portion of the aircraft. The long term goal of this organizational structure is to break the aircraft up into smaller sections and locate the necessary support organizations as close to the aircraft production as possible.

Additionally, BCAG has been working to improve the efficiency and effectiveness of their existing production processes. "In order for BCAG to maintain their stated objective of keeping their 60% market share, they have established a goal of reducing aircraft production costs by 25% by 1998".[6] To achieve this goal, BCAG is implementing many process improvement activities such as cycle time reduction, hardware variability control, and accelerated improvement workshops. There have also been some localized efforts to include TPM programs into the organization's process improvement plans. "By implementing these 'lean manufacturing'[7] activities, Boeing hopes to gain enough efficiency to avoid hiring additional workers to meet the demands of an increasing production rate".[8]

---

[6] The Boeing Company, 1995 Renton Division Business Plan.

[7] For the purposes of this thesis, "Lean Manufacturing" will be considered to be the collection of manufacturing processes and management approaches that focus on: Improving the flexibility of the

The following table shows the steps that an organization would typically go through as part of this lean manufacturing revolution.[9]

Roadmap for Product Team:	Achievements:
1. Awareness Revolution	• Benchmarking for Factory Floor Leaders • Leaders Learning Begins • Begin Daily Debriefs • Training and Learning for Team Members
2. TPM	• Understand "Wasteology" • Implement Autonomous Maintenance • Understand and Apply Visual Controls • Understand TPM Link to JIT
3. Flow Manufacturing	• Set up Key Measures for Manufacturing System • Understand & Apply: One Piece Flow, Kanbans, Pull Production, & Cellular Manufacturing (as appropriate) • Rearrange Flow in Factory • Develop New Job Assignments
4. Leveled Production	• Level Production Schedule & Synchronize Product Flow • Reduce Set-up Times • Defect Prevention in Place (in-process controls) • Understand & Apply: Quality Assurance, Changeover, Producing Same Quantity Daily
5. Standard Operations	• Understand & Apply: Work Sequencing, Maintenance & Safety, Jidoka
6. Lean Manufacturing	• Continue to Reduce Waste & Cycle Time • Add Flexibility to Handle Customer Variation

Figure 3: Lean Manufacturing Roadmap

At the same time that BCAG is improving existing processes, many new manufacturing processes are being introduced as part of the activities to improve their manufacturing

---

production processes to accommodate a variety of products, eliminating the waste in the production system, and reducing product introduction lead time and manufacturing cycle time.

[8] Cole, Jeff, "Boeing Commercial-Jet Unit", *The Wall Street Journal*, February 9, 1996.

[9] The Boeing Company, 1995 757 Fuselage Assembly MBU Business Plan.

capabilities. One of these new processes is based on the concept of using 'self-locating' parts that are assembled via precisely located coordination holes. This is in contrast to the traditional method of using large assembly jigs to force parts into their proper relationship prior to drilling and fastening the assembly. This new assembly process is being applied to the fuselage assembly of several Boeing aircraft. The self-locating concept allows BCAG to eliminate a significant number of assembly fixtures and replace them with a single, flexible, Computer-Numerically Controlled (CNC) work cell. This concept improves the flexibility of the manufacturing system and reduces variation in the production hardware associated with the old tooling fixtures.

1.3 Thesis Content and Structure

The following sections describe the focus of the research, the activities performed during this research, as well as a summary of the results. This section concludes with an overview of the rest of the document.

Problem Statement

Although BCAG is expending considerable energy to improve their production processes, they do not employ a reliable and repeatable method for implementing these process improvements. Further, most of the organizations that are implementing Total Productive Maintenance are only focusing on local improvements, and are not coordinating their efforts to achieve a global optimum for TPM implementation. As a result of this poor coordination, the implementation of Total Productive Maintenance is inconsistent and the results are unpredictable. Additionally, the rest of the process improvement activities being performed as part of BCAG's lean manufacturing implementation are being isolated from each other. Without the linkage between these activities, manufacturing managers have no ability to prioritize between the various process improvement activities. By establishing these linkages, the components of lean manufacturing can achieve a larger degree of synergy, through shared tools and data.

Within BCAG's manufacturing operations, there is no well defined manufacturing strategy evident at the lower levels of the organization. This situation is exacerbated by a shortage of useful and reliable data available to the manufacturing managers. Without reliable data and a well defined strategy, the factory managers are unable to identify their critical processes, let alone focus their scarce resources on improving these processes. Thus, production worker activities and production equipment utilization could well be sub-optimized.

Additionally, many of BCAG's existing approaches to equipment maintenance do not focus on maximizing the effectiveness of this equipment as part of an overall manufacturing system. The current level of maintenance of the equipment is not driven by an understanding of the important role that the manufacturing equipment plays an important role in determining the quality of the production parts. Proper maintenance becomes a high leverage point when automation and advanced technology equipment are brought into the workplace. This new equipment typically assumes more responsibility for quality, due to less employee intervention in the manufacturing process.

Relevant Literature

There is a significant amount of literature available on the subject of Total Productive Maintenance, much of which is fairly similar and provides only small variations on the common themes. The following TPM books were the most useful in developing the definitions, concepts, and methods described in this thesis. The most commonly cited references come from Seiichi Nakajima ("The father of TPM"). His books, "Introduction to TPM" (Productivity Press, 1988) and "TPM Development Program" (Productivity Press, 1989) describe the principal components of a TPM program, document the potential benefits, describe overall equipment effectiveness measurements, and provide sample implementation plans. Nakajima's work has formed the basis for most of the TPM training material that has been developed within BCAG, which was also used extensively in my research. The writings of Terry Wireman ("TPM, An American Approach", Industrial Press, 1991) looks at TPM from the perspective of the maintenance organization. Wireman uses most of Nakjima's basic TPM ideas and describes them in terms of what the changes mean to the individuals that have traditionally performed all maintenance activities. Also, Wireman briefly discusses the concept of TPM being a part of the overall manufacturing system, rather than taking the view of Nakajima, where TPM basically is the manufacturing system. Another prominent TPM authority, Kunio Shirose, describes TPM from the viewpoint of the equipment operators in his book "TPM for Operators" (Productivity Press, 1992). Shirose uses simple and straightforward examples to describe the changes that take place in the equipment operator's roles and responsibilities. Shirose's book provides a nice balance to the Wireman book, since each looks at TPM from the two most affected organizations: maintenance and manufacturing.

Each of these authors, along with virtually all TPM literature, starts with the assumption that TPM is the primary foundation for a manufacturing system. They fail to start with the critical question of: "Is TPM appropriate for the given manufacturing process?". One of the goals of this research is look more objectively at the manufacturing system and decide if there are other process improvement initiatives that may provide more benefits than a TPM program. My research evaluates a handful of TPM projects to develop insight into what types of facilities and processes are ripe for TPM implementation. For example, a fully automated, continuous flow manufacturing facility would likely get more benefits from a TPM program than a manufacturing process composed of small job shops primarily performing simple hand-work operations.

Another drawback to the TPM literature is that they rarely address the issue of how TPM fits in with the existing manufacturing system. As a result, this research on TPM was expanded to include the literature on world class manufacturing and lean manufacturing. Richard Schonberger has written extensively on the topic of world class manufacturing ("World Class Manufacturing", The Free Press, 1986), and briefly discusses the concept of TPM. Also, Peter Reid provides a good selection of lean manufacturing lessons learned by The Harley-Davidson Company in his book "Well Made in America" (McGraw-Hill, 1990). These two books provided the framework used in this thesis to describe how TPM complements the other components of a well functioning manufacturing system. These references were supplemented with books on the specific components of world class/lean manufacturing to identify common elements and overlaps. The component specific books, such as "A New American TQM" by Shoji Shiba et al. (Productivity Press, 1993), provide details on their particular topic, but tend to take an isolationist view. They fail to recognize the other components of the manufacturing system; so once again the higher level framework is required.

The intent of my research was to thoroughly describe TPM, without forgetting about the rest of the manufacturing system and the other improvement initiatives. TPM is described in an environment containing hardware variability control, inventory reduction, and basic housekeeping programs. Also, this research borrows from product development methods, such as Don Clausing's "Total Quality Development" (ASME Press, 1994), to develop methods for implementing new manufacturing processes. The tools used for product development are quite useful when slightly modified to support process development activities.

Research Approach

This research was conducted within BCAG, in the 757 Fuselage Assembly Manufacturing Business Unit (MBU), where Total Productive Maintenance (TPM) has seen only limited exposure. The initial plan was to identify improvement opportunities that could be achieved through TPM implementation; such as reducing hardware variability and thus reducing manufacturing costs in a facility that uses sophisticated production equipment. A TPM implementation plan was to be developed, deployed, and the results analyzed. Unfortunately, these plans had to be modified due to a labor dispute which forced a plant shut down. As a result, the research plans were modified to include the following:

Phase I: Explore the linkages between TPM goals and activities, and the goals and activities of the other major components of lean manufacturing: Just In Time Production, Total Quality Management, and Total Employee Involvement. This phase of the research established the dependencies that exist between these initiatives

Phase II: Develop a composite description of a successful implementation of TPM. This was created from related research work, literature on TPM concepts, benchmarking the existing TPM activities within BCAG, and interviews with individuals that have lead and participated in implementing TPM. The results from this phase of the research provided lessons learned from TPM implementation activities, as well as a description of the components of a desirable TPM program.

Phase III: Develop and document a generic process development and implementation methodology, which was based on several existing product and process development tools. The goal of this phase of the research was to create a 'road map' for other teams to follow when embarking on the task of creating new processes or improving existing ones.

Phase IV: The final phase of this research was to utilize the results of the first three phases to create a TPM implementation plan for the 757 fuselage assembly MBU. Since this MBU is currently bringing new manufacturing processes on line, it provides a timely opportunity to implement new manufacturing concepts, such as TPM. This implementation plan was integrated with other existing manufacturing initiatives to create a cohesive approach for implementing many of the components of lean manufacturing.

Results of Research

The following is a brief summary of the benefits that were realized from this research:

- The documentation of a comprehensive approach for developing and implementing TPM methods. This provides a useful step by step guide for teams to follow when implementing TPM in their organization.
- The linkage between production equipment management and hardware variability was established. The elements of TPM were aligned with the causes of hardware variability to show that TPM can reduce hardware variability and thus reduce manufacturing costs.
- A TPM implementation plan was developed for the 757 FAIT Program. This research provided the FAIT Program with a useful 'jump start' on the activities required to implement TPM.
- The role of TPM was aligned with the other concepts of world class manufacturing/lean manufacturing. This allows management to implement TPM as part of their lean manufacturing practices in an integrated manner. This should eliminate confusion over roles and responsibilities and avoid unnecessary overlaps in activities.

Thesis Structure

Chapter 1 - Introduction

In the opening chapter I have discussed the current situation facing the commercial aircraft industry. This includes a brief summary of the health of the airlines, the competition faced by Boeing, and Boeing's strategy to address the changes in their market. The problems that were addressed in this research, and the approach utilized, were also described in this chapter. I also provide a brief overview of how the remainder of the thesis is structured.

Chapter 2 - Aircraft Fuselage Assembly Methods

This chapter provides information on the various methods used to assemble an aircraft fuselage. This includes the changes that have occurred in the past decade and the technology that has enabled these changes. This chapter introduces the reader to the concept of 'self tooling' and the 757 Fuselage Assembly Improvement Team (FAIT) Program. The sources of hardware variability inherent in these processes are also documented.

Chapter 3 - Total Productive Maintenance Overview

I provide an introduction to the major components of TPM, the benefits of implementing TPM, and describe the situations that are the most appropriate for TPM. I also discuss metrics that are useful for determining the effectiveness of TPM implementation.

Chapter 4 - Analysis of Existing TPM Activities

This chapter provides an overview of several TPM implementation projects within BCAG. The benefits that have been realized, and the challenges that have been faced are documented. I provide a listing of the 'critical success factors' that have helped some of these TPM initiatives to succeed.

Chapter 5 - Implementing TPM in the Fuselage Assembly Process

In this chapter I describe the opportunities for TPM that are created by the introduction of the new aircraft assembly methods. I use the information collected in the previous chapter to provide recommendations on how to successfully utilize TPM, and measure the results, in this particular assembly process.

Chapter 6 - Conclusions and Recommendations

I end the main body of the thesis by summarizing the results of my research activities and discuss how these results can be utilized by others. I provide additional recommendations that are specific to the FAIT Program, as well as recommendations that are applicable to the remainder of BCAG.

Appendix A - Methodology for Process Implementation

This appendix describes a ten step method for developing and implementation new manufacturing processes. This methodology provides a useful roadmap for other teams to follow as they develop their own plans.

Appendix B - Total Productive Maintenance Detailed Description

This appendix provides a more thorough description of the TPM concepts than that provided in chapter 3. An example of calculating overall equipment effectiveness, and its relationship to manufacturing costs is also documented.

Appendix C - Sample TPM Implementation Plan

This appendix contains a step by step description of the tasks required to implement TPM in the 757 Fuselage Assembly process. This plan lists the training requirements, team membership, and resources required for implementation.

2. Aircraft Fuselage Assembly Methods

There has been a major change recently taking place in aircraft assembly processes; new assembly methods are replacing the historical approach to aircraft assembly. The new assembly processes have been enabled by improved Computer-Aided-Design/Computer-Aided-Manufacturing (CAD/CAM) technology. Specifically, engineering datasets are being enriched and used by downstream organizations, such as manufacturing engineering and tool design. Also, the new automated and semi-automated assembly equipment uses this data to manufacture major portions of the fuselage assemblies. This migration toward automated manufacturing equipment has far reaching implications for the operators of the equipment, as well as for the support organizations: maintenance, process engineering, quality assurance, etc. Further, these changes create the need for a new approach to equipment management. The following chapter describes the historical manufacturing approach that is being phased out, as well as the incoming new processes

2.1 Traditional Approach to Fuselage Assembly

The historical design-build process at BCAG has been used for at least the past 25 years. Using this historical approach, products were developed, designs were drawn up and released, and drawings were forwarded to the operations organizations in a 'throw it over the wall' sequential manner. These designs were reviewed by manufacturing engineering and other operations departments and, based on this review, manufacturing plans were developed and released. Using the product designs and plans, tools were then designed and built for assemblies and detail components. Then suppliers fabricated detail parts and shipped them to the assembly shops. When these activities were completed, the assembly plant began assembling the aircraft. Quality assurance inspected the completed parts and assemblies throughout this process.

This design-build process relied heavily on the employee's workmanship and attention to detail in product and tool definition and in manufacturing operations. Continued production of high quality assemblies required a disciplined adherence to the manufacturing process, as well as a touch of craftsmanship. In this case, component fabrication and assembly tooling was largely responsible for controlling the final configuration of the aircraft. Engineering tolerances defined the threshold between good and bad parts, and anything within the tolerance band was considered good. The data collection and quality assurance methods relied on evaluation of completed products, rather than in-process measurements. If a problem was found with a product; the designs, plans, tools, and factory worker were all reviewed to find the source of the problem. Each of the major assembly tools had a log book that tracked the history of modifications, the quality assurance organization had a database containing product rejection histories, and the maintenance staff kept a database of repairs that were performed on the equipment and tools. These three sources of data were not linked or correlated.

Assembly Tooling Development

In his 1993 LFM thesis, Lindsay Anderson documented the history of the Boeing tooling philosophy. The manufacturing approach being described here falls into what he called the "middle generation" of Boeing's tooling history.[10] The tooling requirements for this manufacturing era began with an engineer defining the contour of the airplane based on aerodynamic analysis. This contour information was stored as a series of data points in a digital dataset known as the 'master dimension data' (MDD). This data was then recreated in a separate computing system using APT programming language, which was then used for machining 'master model' tools from whole blocks. These large contoured blocks (the master models) were then used as the authority for the creation of tools for skin panel forming, router fixtures, etc. These forming tools were created by taking a plaster 'splash' off of the master model to transfer the shape of the master model onto the forming tools.

The digital MDD was also used to establish locating points at specific intervals, down the length of the airplane, for each frame position. Master tooling templates were then machined from this data at each of the frame positions. These master tooling templates

---

[10] Anderson, Lindsay, "Assembly Process Development for Commercial Aircraft Using Computer-Aided Tolerance Analysis Tools", MIT Leaders for Manufacturing Program, Masters Thesis, June 1993.

were now used as the authority for the fabrication of assembly fixtures and assembly tools. Gauges to verify the contour of the completed frame assemblies, and the frame assembly tools and fixtures, were also manufactured from the master tooling templates. Although this tooling approach was an improvement over previous tooling philosophies at Boeing, it still depends heavily on data being transferred from physical tool to physical tool. Also, the limited amount of digital data is contained in multiple computing systems. Therefore, there is no means to verify that the data has been translated correctly through all of these steps except by using additional physical tools.

Traditional Assembly Process

The traditional fuselage assembly processes utilized dedicated, non-flexible, routing and assembly tools as well as mylar templates, to trim skins and locate component parts to fuselage panels. Few fuselage panel assemblies share the same tools; one assembly fixture was typically used for each panel assembly in each major operation. Most panel assemblies had two or three mylar templates due to the size and complexity of assembly operations. The assembly fixtures held the parts to rigid locating points while mylar templates assisted the assembly mechanic in locating temporary attachment holes. The assembly mechanic manually drilled temporary attachment holes through two or more component parts while the tooling held them in location. After first locating and drilling the components, they could be removed from the fixtures, deburred (rough edges caused by drilling are removed), sealed (corrosion inhibiting adhesive is applied), and then manually reassembled without being loaded back into the tooling fixtures. Temporary tack fasteners were inserted through the temporary attachment holes to hold components together while the remaining fasteners were drilled and riveted with one of the large semi-automated riveters.

Drawbacks to Traditional Assembly Process

The traditional method of aircraft fuselage assembly has been adequate and has stood the test of time. These methods were simple, reliable, and met the basic objectives of aircraft fuselage assembly. However, these methods also have a significant number of drawbacks. The more significant of these drawbacks are summarized below.

- The dedicated, non-flexible, fixtured tooling has proven to be a hindrance for incorporating changes in aircraft configurations. The assembly tools must be significantly reworked and re-machined to accommodate changes in customer requirements.
- The final product is essentially built to 'as-built' tooling rather than the theoretical engineering definition. The accumulation of variation during the tool design and fabrication processes, as well as during component fabrication processes, directly contributes to variability in the final product.
- Many of the fixtured tools use different index points to locate components and sub-assemblies throughout the process. The multiple indexing of components and sub-assemblies creates variability that accumulates during the assembly build up process.
- The assembly tools and processes are very sensitive to part variation since they typically locate off from one end of a component. This forces all of the part variation in one direction instead of centering it over the true intended position.
- There is no verification process to ensure that the parts will fit per drawing, much less when including component manufacturing variation. Since the engineering data is stored in multiple systems, there is no means to analyze the entire assembly design to verify that the design is manufacturable.
- The assembly quality is largely dependent on the tool accuracy and assembly mechanic's skill. This has created the "pound to fit, paint to match" mentality in the production shops. Obviously the assemblies must conform to engineering specifications for structural integrity, but there are excessive amounts of rework involved in achieving these requirements.
- Data collection was performed 'after the fact'. Little in-process monitoring was used to identify potential problems before bad parts were produced. Also, there was minimal effort to determine process capabilities, to verify that the production equipment was capable of producing parts that would meet engineering specifications.
- The maintenance performed on the tools and equipment was primarily breakdown repair, and had virtually no operator involvement in inspections and maintenance. Also,

there was very little proactive maintenance, and most planned maintenance was determined by calendar days rather than by equipment usage or need.

This list of drawbacks contains several examples of the sources of assembly variation that are inherent in the traditional assembly methods. In an effort to provide a more complete list of the causes of assembly variation, the following Ishikawa (fishbone) diagram was constructed as part of a previous study on the variation of parts and tools in aircraft production.[11] The principal sources of assembly variation have been identified in the bold format.

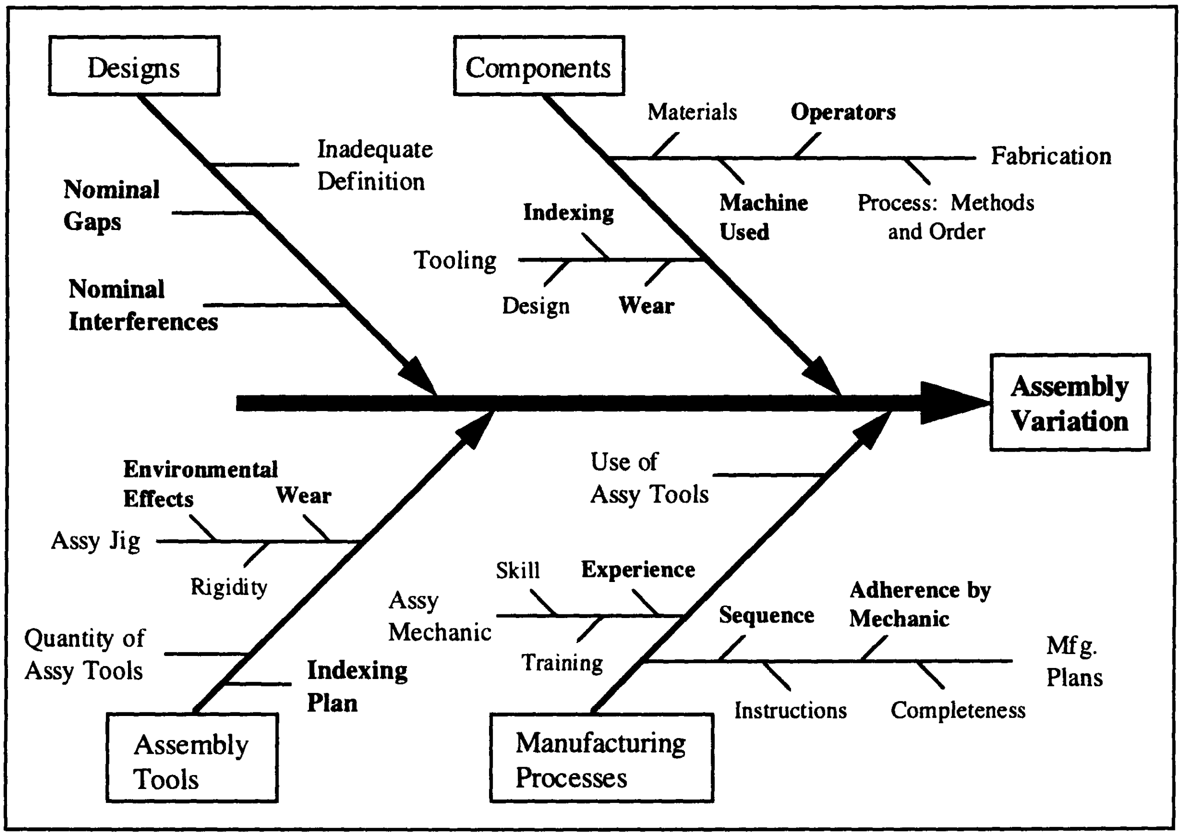

Figure 4: Sources of Variation in Traditional Assembly Process

In light of Boeing's need to satisfy the diverse requirements of their airline customers in an ever increasingly competitive market, it eventually became apparent that this traditional assembly method would no longer be sufficient. These traditional methods did not allow

---

[11] Shalon, Dari, "Indexed Pre-Assembly with Variations; A Method of Representing Variations of Parts and Tools in CATIA", MIT Leaders for Manufacturing Program, Masters Thesis, June 1992.

rapid changes in product configuration, nor could the manufacturing system quickly adjust to changing production schedules. Boeing needed to develop a method of aircraft assembly that increased the flexibility of the factory to quickly adjust to customer requirements, while reducing cycle time and improving product quality. This would provide Boeing with a competitive advantage by reducing new product lead time and allowing faster responses to changing market demands. At this same time, Boeing was becoming increasingly aware of the excessive costs associated with manufacturing processes with inadequate control of variation in part and assembly dimensions. The previous Ishikawa diagram is certainly not comprehensive, yet it portrays the significance and the diversity of the factors that were introducing variation into Boeing's aircraft. The result of these concerns, and competitive marketplace pressure, was to develop a new process for assembling aircraft fuselages.

2.2 Accurate Fuselage Assembly Process

The recent advancement in aircraft fuselage assembly methods described here is known by many names: Determinate Assembly, Advanced Technology Assembly, or Accurate Fuselage Assembly. For the purposes of this thesis I will use the Accurate Fuselage Assembly (AFA) name which was coined by the Fuselage Assembly Improvement Team (FAIT) of BCAG's Renton Division. The basic premise of the AFA process is the utilization of spatial relationships between key features of detail parts or sub-assemblies. These features are defined in the digital design, and are controlled by numerically driven machine tools. This approach uses precisely located coordination holes to determine the relative location of detail parts and sub-assemblies, making these parts essentially self-tooling. This approach significantly reduces the fixtured tooling requirements over the traditional assembly process.

Overview of Accurate Fuselage Assembly

The AFA concept requires that fuselage parts be located relative to each other by common fastener holes instead of hard tooling. These locating/coordination holes are precisely drilled in assembly sub-components by Computer-Numerically Controlled (CNC) equipment using locations which are defined by the engineering dataset. These hole locations are adjusted real-time, using in-process data collection, to account for detail component variation as well as temperature effects. This enables the parts to be 'self-locating', where the assembly is built up by pinning the components together via the coordination holes. The traditional hard locating tools are not required, and are replaced with simple holding fixtures which do not constrain the product configuration. The end result is that the assembly process now uses the engineering drawing as the configuration control authority, rather than the rigid assembly tooling.

The objectives of the AFA process are the following: [12]

- Reduce variation of key dimensions in products and processes:
    - Produce dimensionally stable aircraft fuselage sections built per engineering models
    - Reduce variation of key dimensions in components, sub-assemblies, and assemblies
    - Establish and implement in-process controls to monitor assembly processes
- Reduce overall cost of the 757 fuselage
    - Reduce rework and associated overtime
    - Eliminate unnecessary shimming and trimming
- Reduce 757 fuselage assembly cycle time

To implement the AFA process the 757 FAIT Program initially analyzed the entire 757 fuselage assembly process, to determine the appropriate implementation sequence. This analysis provided the opportunity to collect baseline data, as well as to stabilize the existing assembly process. This team also elected to work with the existing 757 designs to minimize the initial implementation costs associated with redesigning the aircraft assemblies. Additionally, the team chose to work with the existing supplier base and help them improve their component quality, rather than look for new suppliers with potentially superior manufacturing capabilities. From the beginning of the AFA process development, the team developed the attitude of concentrating on the 'vital few' changes required. This helped the team to focus on attacking the items that had the most leverage for improving the traditional process. As a result, the component and sub-assembly designs and manufacturing processes were modified only if absolutely necessary.

---

[12] "Fuselage Assembly Improvement Team Program Plan", Boeing Documentation, 1993.

The development process for the AFA concept on the 757 FAIT program consisted of the following steps:[13]

1. Identify critical detail components and sub-assemblies, based on assembly level requirements.
2. Establish the minimum number of Key Characteristics (KC's)[14] that flow from the top assembly level down to the detail components needed to satisfy assembly requirements.
3. Measure the KC's of the detail components and sub-assemblies. To provide an evaluation of the existing component manufacturing process.
4. Evaluate the existing assembly process and measure the process capability.
5. Perform feasibility studies on the capability of migrating existing assemblies to the AFA concept based on perceived abilities of the AFA equipment.
6. If the assembly is feasible for the AFA process, incorporate this assembly into the FAIT manufacturing plan. If not, work to modify the existing process so that it can be converted to the AFA concept. If it is still not feasible to incorporate this assembly, provide this data to existing improvement teams that focus on the traditional manufacturing process.

Accurate Fuselage Assembly Process

The AFA process requires that the engineering datasets for fuselage assemblies be created using the CATIA™ computing system. CATIA™ is a CAD/CAM system that provides the necessary functions for the engineering design, as well as the required enhancements for manufacturing operations to the dataset. The engineering dataset is used by manufacturing engineering to develop manufacturing plans, assembly sequencing requirements, and Numerical Control (NC) programs. Tool design engineering also uses the dataset to design and build flexible tooling for locating sub-components according to the

---

[13] Ibid.

[14] A key characteristic is defined by BCAG document D1-9000 as: "Features or attributes of a material, part, assembly, or system in which variation from nominal has the most adverse effect upon fit, performance or service life".

engineering definitions. The tool indexing reference points are directly related to the design engineering reference points, which eliminates unwanted tolerance stack-up.

Highly accurate Computer-Numerically Controlled (CNC) machines are used to net trim the periphery of the skin panels and to drill coordination holes in detail parts and sub-assemblies. The equipment necessary for the AFA process includes: a large 5-axis CNC machine to drill coordination holes in skin panels and to trim the panels, a CNC stringer/stringer clip drilling machine for drilling the stringer assemblies, a 3-axis CNC machine to drill coordination holes in frames, and a CNC shear tie drilling machine. Each of these CNC machines are operated as separate manufacturing cells. Each manufacturing cell consists of a CNC machine with reconfigurable tooling that can accommodate several assembly configurations.

The 5-axis machine's manufacturing cell has the capability to drill coordination holes to match stringers to shear ties and doublers to body panels, full-size holes to match stringer clips to stringers, coordination holes to match stringer clips to frames, and coordination holes to match floor beams to frames. The machine will also net trim the periphery of body panels. These operations are performed by using a reconfigurable holding fixture similar to a 'bed of nails'. The 5-axis CNC machine has a variety of end-effectors which allow the machine to drill various sized holes, trim panels, and probe the fixtures and parts to collect SPC data.

The CNC stringer/stringer clip drilling machine drills coordination holes in stringers common to the skin panels, and in stringer clips common to body frames. The machine also locates stringer clips on the stringer at the proper location and match-drills full size holes common to the stringer and stringer clip.

The 3-axis CNC frame drilling machine drills coordination holes in the body frames common to the stringer clips and the floor grid. This machine also drills the holes necessary to build up the frame assembly, and to attach a variable selection of brackets.

The CNC shear tie drilling machine drills coordination holes in shear ties common to the fuselage skin panels. The shear tie machine also optically measures each component prior to performing the drilling operation to create a best fit between the NC program and the physical part. This measurement data is downloaded to a database in case it is needed for later analysis to resolve downstream quality problems.

The final riveting operations are performed by existing semi-automated drivematic riveters. These are the same equipment that were used with the old assembly process.

These assembly techniques are currently being used to produce the constant contour body sections of the 757 aircraft. Additionally, these concepts are being slightly modified for use on the 747 floor grid assembly, the 777 fuselage assembly, the next-generation 737 fuselage assembly, and some portions of various aircraft wings and doors.

Enabling Technology

The Accurate Fuselage Assembly process was simply not economically feasible prior to the recent advancements in CAD/CAM and CNC technology. The ability of CAD/CAM systems to handle extremely large quantities of complex geometry was a prerequisite of the full implementation of AFA methods. Also, advancements in machine tool accuracy, repeatability, and reliability were required to make this process economically viable. The following section provides additional insight into these enabling technologies.

Role of CAD/CAM Technology

The AFA process depends on a 'sole source' of data for all parties to work from. This common data source is the CAD engineering dataset, and is used to create manufacturing plans, NC programs, and tool designs. The existence of the sole authority dataset ensures data consistency and also eliminates the confusion created when working from multiple data sources.

The engineering definition takes on multiple views, such as 3-D solid models which can be used to verify that the nominal designs will fit together as intended. This process is commonly referred to as Digital Pre-Assembly (DPA). Assembling the components on the computer often prevents the costly problem of discovering fit-up problems when the first assembly is manufactured. The other method to avoid these assembly problems is to build a physical mock-up of the assembly prior to production ramp-up. The physical mock-up is an extremely costly process, which has minimal benefit after its initial use.

However, the FAIT Program elected to minimize the use of DPA. The belief was that since they had successfully built the 757 fuselage assembly for years, the additional effort required to create 3-D solid models, and assemble them on the computer, would not provide sufficient benefits. Also, the DPA process is not a panacea for guaranteeing a problem free assembly. DPA typically does not include the component-to-tool interface. Nor does DPA address fit-up problems introduced by production variation. Lastly, DPA does not provide assembly sequencing determination.

The introduction of 3-D solid models of production tools into the DPA database of engineering models has allowed for interference checking between parts and tools. This method of 'tooling DPA' was quite usefull for the FAIT program, since they were designing a significant number of new tools. As a result, only the critical interfaces between parts and tools were evaluated using the DPA process.

The recent development of Digital Assembly Sequencing (DAS) technology has provided manufacturing engineers with a tool for determining the optimal assembly sequence prior to any component or tool fabrication. The DAS process allows the manufacturing engineer to participate in the digital design process by adding attributes to the digital models that identify their installation sequence for a given assembly. The assembly sequence can easily be modified to evaluate the effects of changing sequences or changing indexing schemes. Unfortunately, the DAS process was not developed in time for the original FAIT plans; however, revisions to the original plans have been able to benefit.

The final shortcoming of DPA: inability to include manufacturing variation effects, has also been addressed. Although not as elegant as the tooling DPA or the DAS methods, the engineering design can be analyzed for susceptibility to manufacturing variation. One of these analysis methods is known as "Index Pre-Assembly with Variation" (IPAV).[15] Essentially, this method is based on determining local indexes on mating surfaces (part-to-part or part-to-tool mating features). Using these local indexes, the location of a component can be determined within a global coordinate system by summing the distances

---

[15] Shalon, Dari, "Indexed Pre-Assembly with Variations; A Method of Representing Variations of Parts and Tools in CATIA", MIT Leaders for Manufacturing Program, Masters Thesis, June 1992.

from a succession of mating parts. By introducing slight variation in the local index system, the resulting effect on the overall assembly can be calculated. Unfortunately, this approach is fairly computationally intensive due to the necessary matrix manipulation in the three-dimensional case. An alternative to IPAV is to use commercially available software that performs a similar analysis.

In his 1993 LFM masters thesis, Lindsay Anderson evaluated the benefits of using a CAD based assembly variation simulation tool. This simulation tool utilizes the CAD geometry to perform a Monte Carlo random number simulation. The simulation operator identifies the critical features of the design which are allowed to vary with each individual iteration of the simulation. The results of this simulation provide data on those features of the assembly components that have the greatest impact on the overall assembly variation.

The above descriptions are a significant simplification of these two methods of predicting the impact of manufacturing variation on the assembly. I would encourage the interested reader to review the additional information available in the LFM theses of Anderson and Shalon.

The FAIT Program made limited use of these assembly variation analysis tools, due to their complexity and the required investment in time and effort. The assemblies were only analyzed in areas where a significant number of components came together, or the assembly was critical to product quality. This approach is an example of the FAIT Program's attitude toward focusing on the 'vital few' opportunities to make maximum gains. This is commonly referred to as the 80/20 rule: getting 80% of the benefits, while only investing 20% of the total effort. This rule works well in many situations where it is believed that there are diminishing returns from increased effort.

Manufacturing Equipment Technology

"Only in the last few years have CNC machine tools been available with the accuracy, repeatability, axis lengths, and computer control systems sufficient for the AFA process." [16] The CNC work cells utilize flexible holding fixtures capable of holding different contour

---

[16] Monk, Clayton and Dave Strand, "Accurate Fuselage Panel Assembly Cell", Boeing Documentation.

components, different length components, and different quantities of components in the same fixturing systems. One example of this flexibility is a fixture which employs a vertical 'bed of nails', that has multiple plungers that can be programmed to different contour configurations. Skin panels are held to the plungers using vacuum activated suction cups. The larger CNC equipment are also programmed to accommodate for environmental factors such as thermal expansion. The NC program is calibrated to operate at a specific temperature. If the ambient temperature varies from this reference point, the program and equipment automatically compensate for the resulting shrinkage or growth when performing indexing, trimming, and drilling operations. This ability becomes increasingly critical for larger and larger components. The CNC work cells also have the capability to use a large variety of interchangeable end-effectors. These end-effectors perform functions ranging from drilling, to trimming, to probing for part positioning and data collection. The end-effectors are stored within the work cell to allow rapid changes.

Changes in Organization Culture

The introduction of the new AFA method has had a significant impact on the individuals involved in the aircraft assembly. This applies not only to the assembly mechanics that are performing the assembly steps, but also to the people that work in the various support functions. This section describes some of the more visible changes that have occurred as a result of the implementation of the AFA process.

Cross-Functional Teams

First and foremost, the development and implementation of the AFA process has required a great deal of teamwork. The people that have been involved in the AFA process have worked in a cross-functional, Design-Build-Team (DBT) environment. By bringing all of the affected players together, the DBT's were able to improve their coordination and avoid many of the headaches commonly associated with a new process introduction. The membership of the team changed as the project moved from research and development activities to pilot implementation to full production. However, several key members stayed with the project through its life cycle, and are still actively involved in the AFA process.

Fortunately, the DBT's had factory mechanic involvement from the beginning to make certain that the final customer of this new process always had a voice in the project's direction (the factory mechanics became the equipment operators). Additionally, research and development engineers are still involved to help develop improvements to the existing AFA process. These engineers are also sharing their lessons learned with the new teams that are actively working on the next generation of aircraft assembly. This team environment has followed the process out to the factory floor. The new organization structure of responsibility centers and manufacturing business units has allowed most of the manufacturing support functions to stay closely aligned with the products.

Revised Roles and Responsibilities

The AFA process requires several organizations to develop new areas of expertise. For example, manufacturing engineering has seen a significant increase in the amount and complexity of their NC programming workload. This organization has also had to develop new skills in assembly sequencing methods and variation analysis. The quality assurance organization has seen their function change from hand inspecting finished hardware to analyzing automatically collected data. Quality assurance has also had to address the issue of how to best utilize this newly available data for decision making. This is no small issue, since changes in quality assurance procedures typically require airline customer involvement, as well as FAA approval.

Arguably the most affected people in the new AFA process are those in the manufacturing organizations. The shop floor assembly mechanics have seen their jobs change radically. They are no longer required to make minor adjustments to the parts as they are located in the tools. Their vast experience at achieving a best fit between all of the parts and the tools is no longer valuable. Assembly mechanics have long been rewarded on their ability to hand-craft a high quality assembly. This was often done in the face of adversity with tools, plans, and designs that were less than perfect. The new CNC production equipment has eliminated much of this responsibility. Now the assembly mechanics must be skilled at working at a computer terminal to download NC programs, and must learn about data analysis and interpretation. This makes them the first line of defense when manufacturing equipment anomalies occur. The assembly mechanics have passed much of their knowledge and skill to the designers and programmers of the CNC manufacturing equipment. Now this knowledge is imbedded in the equipment that they operate.

The diminished role of human interaction with the assembly build-up has removed much of the traditional unofficial quality assurance from the hands of the assembly mechanics. Where the production tools traditionally supported the assembly mechanic function; now the assembly mechanics support the production equipment, and they become equipment operators. Historically the equipment was not given nearly the level of responsibility that it now possesses. Since advanced CNC equipment now has almost total control of the assembly quality, any variation in the equipment will directly translate into variation in the aircraft assembly. The new production equipment has now assumed a more dominant role in the manufacturing process.

As a result of the increased dependence on equipment performance to determine product quality, the maintenance organization supporting the equipment now has increased visibility and importance. The maintenance staff has had to increase their skills in maintaining these more complex machines. Further, this high cost equipment typically does not have a back-up system, which increases the pressure on the maintenance organization to avoid any unscheduled downtime. This pressure is magnified by the fact that this equipment is also the bottleneck step in the assembly operation. Equipment breakdowns, or allowing equipment to wear enough to produce bad parts, affects the entire assembly line. These types of manufacturing problems can often be minimized if the maintenance organization adopts the concepts of Total Productive Maintenance (TPM). By implementing TPM, the maintenance staff can begin to use the skills of the equipment operators (assembly mechanics) to perform the daily inspection and routine maintenance tasks. Also, the maintenance staff can use the data generated by the equipment operators as a precursor of any equipment malfunctions. This allows the maintenance organization to expend more effort on proactive maintenance and thus avoid unplanned downtime. TPM will be described in greater detail in Chapter 3.

Another group affected by these changes is the organization representing many of the people described above: the assembly mechanic, maintenance mechanic and maintenance technician unions. These unions have had to make many adjustments to accommodate the impact of these new manufacturing processes. Since, union representatives have been involved in the AFA process from the beginning, they have had an opportunity to address issues such as changing roles and responsibilities, and training for new skill requirements. One of the reasons for the success of the AFA process is that it has allowed many of the affected employees to increase their value to the company by acquiring additional skills.

Overseeing these changes in the manufacturing process has created new challenges for the management team. Many of the managers have recognized these changing roles and have modified their business plans and incentive systems to support the new processes. These managers have attempted to move decision making down to lower levels to empower the employees with appropriate ownership and authority. However, there are still some managers that focus only on schedule and machine utilization rates. This forces the manufacturing system to produce unnecessary inventory, just to keep the equipment running. Also, these 'old school' managers typically retain virtually all decision making authority. To maximize the benefits of the new manufacturing process, and get the best out of the employees, these managers need to be phased out through training or replacement.

Accurate Fuselage Assembly Risks

With any new process, there is always some element of risk, and the AFA process is no exception to this rule. The AFA process exposed the assembly operation to a risk inherent in most automated processes: it does not accommodate variation in the component dimensions. A robot simply can't make the necessary adjustments when incoming parts do not fit into the holding fixtures. This situation increases the variation reduction requirements imposed upon the up-stream suppliers. Fortunately, in the case of the AFA process, the sub-components do not vary enough to cause any significant problems for the loading and holding fixtures.

Another risk element that must be accounted for is the introduction of errors during the drawing conversions required by the new process. In the case of AFA, many of the engineering designs were converted from old mylar drawings to CAD datasets. Any mistakes made during this process ultimately results in producing bad designs, which leads to bad manufacturing plans, tool designs, and production parts. Due to the criticality of these potential errors the FAIT Program performed extensive analysis and checking of the designs prior to releasing them to tooling and manufacturing. Since FAIT chose to minimize the use of DPA and other CAD tools, this design verification was a rather labor intensive checking task.

A third area of risk stems from the fact that the new production equipment has an increased impact on assembly quality. As previously stated, the AFA process has minimized the role of the assembly mechanic as a craftsman by reducing the variation of the assemblies key characteristics. The assembly process is reduced to basically pinning the components together via their coordination holes. Excessive variation in the location of these coordination holes inhibits assembly, so the sub-components can't be sent through the remaining assembly riveting steps. To reduce the magnitude of this risk, the FAIT Program increased their equipment performance requirements by establishing targets for process capability (Cpk > 2.0). Achieving these targets required additional data collection and new quality assurance methods, such as in-process inspection, for the key characteristics. Additionally, equipment management and maintenance methods needed to be modified to ensure that the equipment's performance was not allowed to significantly degrade. As a result of this, the maintenance organization started performing additional equipment inspections, and enlisted the help of the equipment operators to keep the work cell cleaned.

The final element of risk that I would like to address concerns the increased dependence on the equipment reliability. The high cost of these new CNC work cells makes it economically unfeasible to have redundant systems. Without a back-up system for this major assembly process, any unscheduled downtime has a major impact on the rest of the manufacturing system. Also, the nature of this assembly process makes it impossible to pass partially completed assemblies on to the next steps in the manufacturing process. In essence, incomplete jobs can no longer be 'traveled' to the next assembly position. Further, the new equipment was designed with a specific production rate in mind. As the overall production rate increases to this limit, the new equipment becomes the production line 'bottleneck'. According to the popular Theory of Constraints, "the cost of any downtime on your bottleneck is equivalent to the cost of your entire production system".[17] Even if one doesn't completely agree with the Theory of Constraints, it is easy to see the significant impact of any unplanned downtime on the equipment that paces the assembly operations.

Accurate Fuselage Assembly Benefits

Recall that the goal of the AFA process is to significantly improve product quality and consistency, and increase manufacturing process flexibility. To help accomplish these goals, the FAIT Program adopted a rigorous Hardware Variability Control (HVC) approach. Their approach employed the concept of key characteristics to identify the bare minimum of critical component features, and can be summarized by the following:[18]

- Limit the number of key characteristics on drawings
  - Introduce them only when absolutely necessary
  - Minimize the need for measurements
  - Avoid establishment of 'unnecessary requirements'
- Concentrate only on top assembly key characteristics
  - Measure detail parts only if necessary
- Control the coordination hole drilling process
  - Implement in-process controls
  - Index parts to minimize the effects of sub-component variation
  - Establish and measure process capabilities
  - Implement a TPM plan

The implementation of this approach started at the very beginning of the FAIT program, where critical component and assembly features were identified early in the process so that the manufacturing plans and tool designs could include these requirements. As existing engineering designs were converted from mylar to CAD format they were evaluated for criticality to assembly quality. The team would determine the allowable amount of variation

---

[17] Goldratt, Eliyahu M., "The Goal", Great Barrington, MA, North River Press, 1992.

[18] "Fuselage Assembly Improvement Team Program Plan", Boeing Documentation, 1993.

in part features for each sub-component such that overall assembly requirements were met. The goal of this analysis was to avoid revising existing designs, while maintaining the quality of the assembly. By knowing the capability of their production equipment at both the assembly and component level, the team was able to allocate the critical components and assemblies to the more capable manufacturing processes. This part-to-process allocation approach is preferred to simply tightening the tolerances on the critical part designs, which just results in more rejected parts (since the same old manufacturing process can not meet the new design constraints). The other option is to improve the process capability by improving the equipment's accuracy and repeatability.

The benefit of this part-to-process alignment is based on the assumption that the variation at the assembly level is essentially the sum of the variation in the sub-components. For example, in a typical assembly the oversized components will theoretically compensate for undersized components (on average) such that the total assembly variation will rarely produce the theoretical worst case scenario. This approach of "statistical tolerancing"[19] assumes that the variation in the key characteristics of the detail part is 'normally distributed'. Therefore, the variance in the assembly level key characteristics can be determined by the sum of the sub-component variance. The following equation is used to determine the assembly key characteristic variance:

$$\sigma^2_{(assembly)} = \sigma^2_{(part1)} + \sigma^2_{(part2)} + \sigma^2_{(part3)} + \ldots$$

Where $\sigma^2_{(assembly)}$ is the variance of the assembly key characteristic. This equation shows the relationship between the variability in the individual components and the subsequent assembly variability. Using this design for assembly approach, the team also effectively identified the manufacturing processes that required improvement in order to achieve the assembly level requirements. By improving the capability of the manufacturing processes that produce the critical components (as identified by the key characteristic flowdown), the benefit to the assembly can be maximized. Also, the team avoids the cost of improving processes that are not related to determining the key characteristic features.

---

[19] Hippe, Dan, "757 Fuselage Assembly Tolerance Analysis", Boeing Documentation, 1995.

To ensure that the AFA process continues to perform as designed, the following control metrics were established:

- Daily machine probing to validate machine tool and fixture alignment
- Periodic measurement of parts and assemblies to calculate process capability and identify performance degradation
- Periodic preventive maintenance to minimize unexpected breakdowns

These controls provide frequent data collection opportunities. These data can then be analyzed using various short run Statistical Process Control (SPC) techniques to determine process performance. This approach prevents the data overload that can result from collecting SPC data on every operation performed by every piece of equipment on every component. However, the flip side of this is that there may be insufficient data to reliably identify process problems before bad parts are produced.

Sources of Hardware Variability Reduced

Control of variation of key characteristics, when properly done, reduces the cost of delays and rework, as well as assembly times. If improperly done, it is possible to increase scrap and rework to the point where the manufacturing costs are increased even if assembly time is reduced. The Accurate Fuselage Assembly process reduces, or eliminates, several of the sources of assembly variation that were previously discussed:

- Nominal design fit-up problems have been reduced via DPA techniques on critical interfaces
- Variation in tool fabrication is minimized by working from CAD datasets rather than from physical models
- Engineering and tooling designs account for manufacturing variation through the use and control of key characteristics, including assembly simulation methods
- Data communication errors are reduced by everyone working from the sole source dataset

The following Ishikawa (fishbone) diagram graphically shows how the AFA process has attacked many causes of assembly variation. Once again, the principal sources of variation are identified in bold.

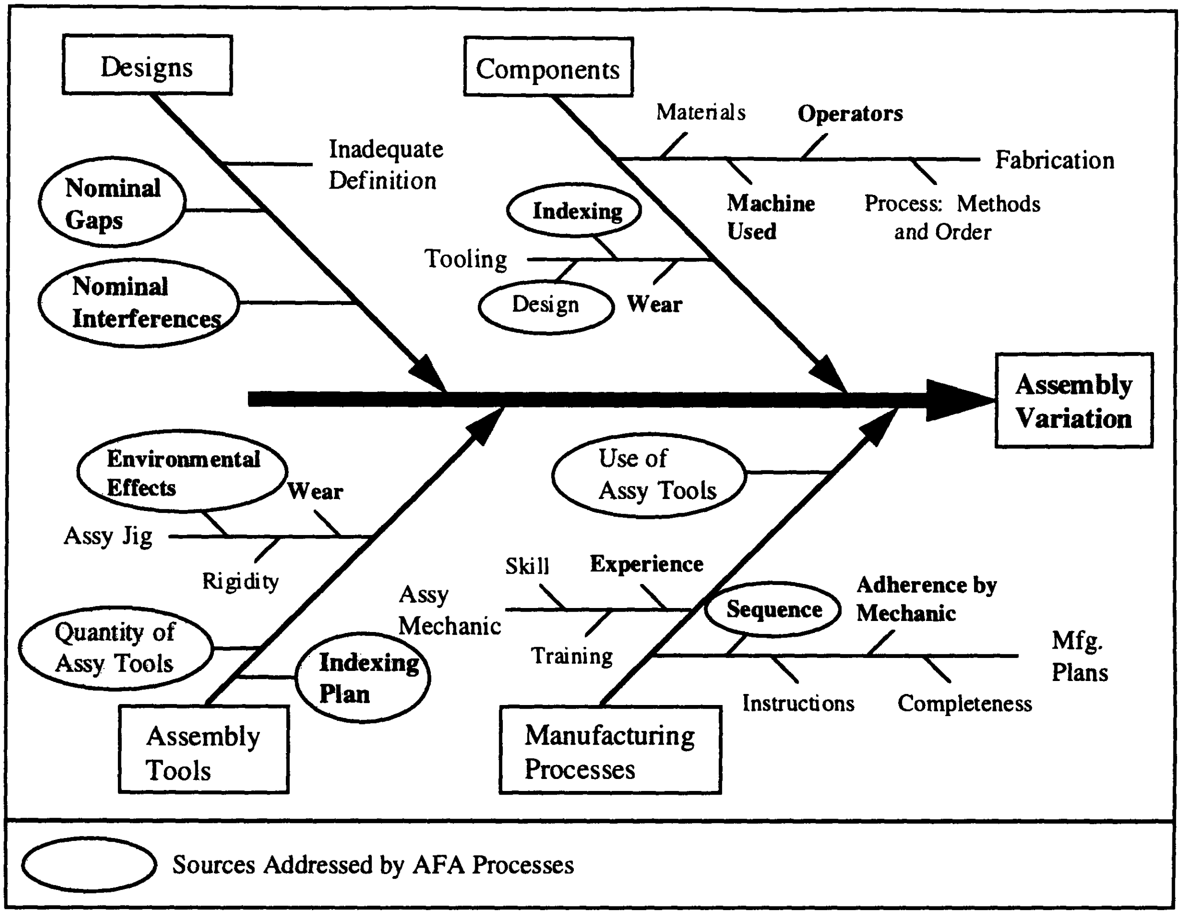

Figure 5: Sources of Assembly Variation After AFA Implementation

However, not all of the sources of variation have been addressed by the AFA process. Fortunately, the AFA process can be supplemented with Total Productive Maintenance[20] to remove a few more of the causes of assembly variation.

Role of Total Productive Maintenance

By this point, it should be obvious that the quality of the assembly is heavily dependent on the capability of the manufacturing equipment in the AFA process. Additionally, the AFA production equipment is now the pacing item for the remainder of the fuselage assembly operations. The activities contained within Total Productive Maintenance (TPM) are well suited to maximize the effectiveness and realizable benefits of this equipment.

[20] Total Productive Maintenance is explained in overview format in Chapter 3, and described in detail in Appendix B. Also, Appendix C provides an example of a TPM implementation plan.

Also, as can be seen in the following diagram, TPM addresses several of the remaining sources of assembly variation.

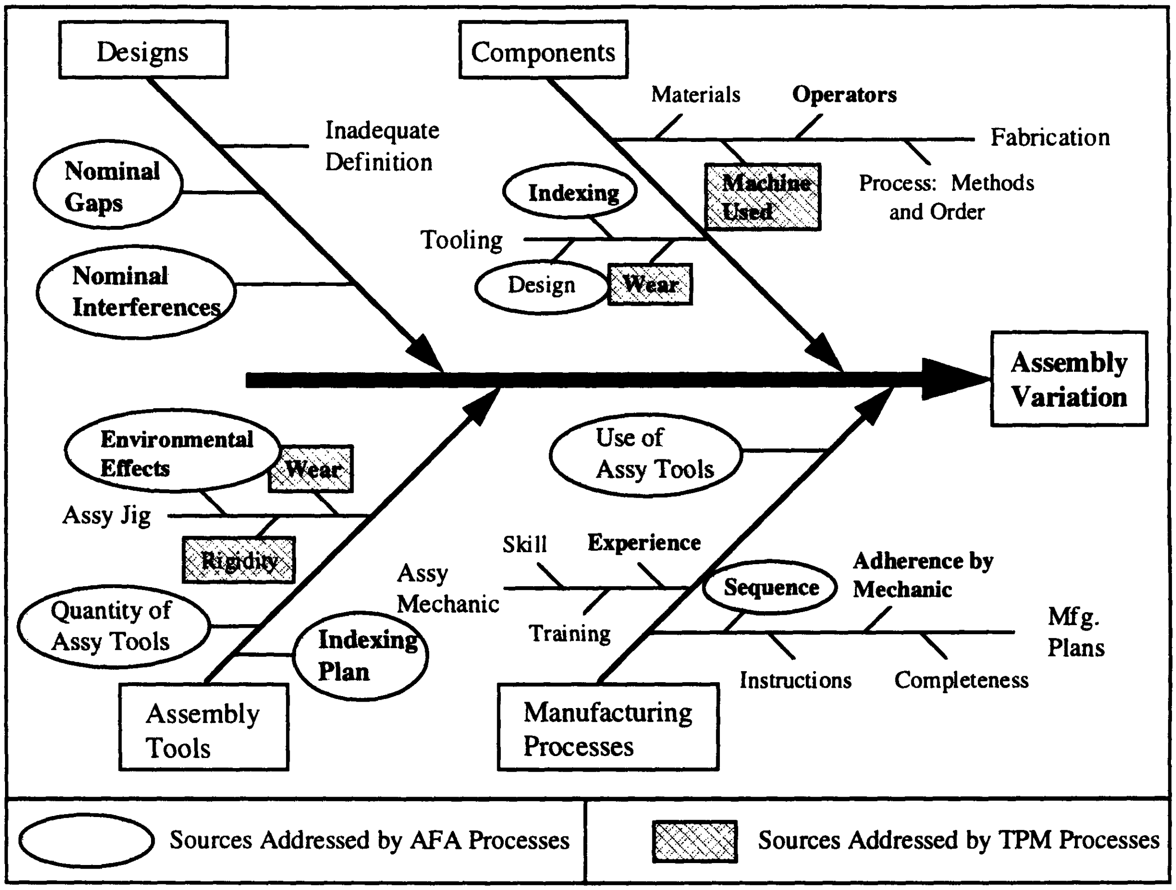

Figure 6: Sources of Assembly Variation After AFA and TPM Implementation

TPM also includes set-up reduction activities, which will help increase the potential throughput of the bottleneck operations on the AFA equipment. This essentially increases the production capacity of the overall assembly operation until the next slowest operation becomes the new bottleneck. Also, performing regularly scheduled capability studies on the equipment, as part of the TPM program, provides data that is beneficial to both the maintenance organization and the quality assurance organization. The data from a capability study shows how well the equipment can reliably and repeatedly perform a specified set of operations. By frequently running these studies, any trends in performance (such as performance degradation due to wear) can be identified. Finally, implementing TPM supports the organization's planned transition toward a more efficient and effective manufacturing system. As part of this transition, the existing production system is in the process of changing to implement pull production and Just In Time (JIT) scheduling. This scheduling approach removes the in-process inventory, which makes the manufacturing system behave more like a continuous flow operation. With no excess inventory in the system to provide a buffer between subsequent manufacturing operations, equipment reliability becomes paramount, since any unplanned downtime affects the entire system.

Summary

The Accurate Fuselage Assembly process uses CNC machines driven by CAD/CAM generated data to drill coordination holes in fuselage assembly components. The process integrates engineering and operations activities to develop assembly processes and tooling concepts that maximize the effectiveness, efficiency and accuracy of the 757 fuselage assembly process. By using flexible tooling, reducing variation, and focusing on defect prevention, the AFA process has reduced production flowtime, reduced inventory, increased responsiveness to change, and increased customer satisfaction. To date, the AFA process has successfully produced over 3,000 fuselage panel assemblies with no scrapped parts. The process is now being deployed to other assembly operations, including compound contour assemblies. In effect, the AFA process has become the de-facto standard for future fuselage assembly methods at BCAG.

3. Total Productive Maintenance Overview

This chapter provides the reader with an overview of the primary elements of Total Productive Maintenance. The goals and objectives of TPM are discussed, as well as the benefits of implementing TPM. Additionally, the feasibility of successfully implementing TPM and reaping the advertised benefits is discussed. Finally, a simplified example of a TPM implementation plan is presented to give the reader insight into what is required to receive the benefits of TPM. For the reader interested in additional details on TPM, Appendix B provides a more thorough discussion of the subject.

3.1 Introduction to TPM

Total Productive Maintenance (TPM) provides a comprehensive, life cycle approach, to equipment management that minimizes equipment failures, production defects, and accidents. It involves everyone in the organization, from top level management to production mechanics, and production support groups to outside suppliers. The objective is to continuously improve the availability and prevent the degradation of equipment to achieve maximum effectiveness. These objectives require strong management support as well as continuous use of work teams and small group activities to achieve incremental improvements. TPM is not a radically new idea, it is simply the next step in the evolution of good maintenance practices.

Equipment maintenance has matured from its early approach of 'breakdown maintenance'. In the beginning, the primary function of maintenance was to get the equipment back up and running, after it had broken down, where the attitude of the equipment operators was one of "I run it, you fix it". The next phase of the maintenance history was the implementation of 'preventive maintenance'. This approach to maintenance was based on the belief that if you occasionally stopped the equipment and performed regularly scheduled maintenance, the catastrophic breakdowns could be avoided. The next generation of maintenance brings us to TPM. In TPM, maintenance is recognized as a valuable resource. "The maintenance organization now has a role in making the business more profitable and the manufacturing system more competitive by continuously improving the capability of the equipment, as well as making the practice of maintenance more efficient".[21] To gain the full benefits of TPM, it must be applied in the proper amounts, in the proper situations, and be integrated with the manufacturing system and other improvement initiatives.

3.2 TPM Concepts

Different sources provide several different descriptions of what makes up Total Productive Maintenance. Some list five different concepts, others list up to seven different concepts that fall under the umbrella of TPM. Rather than try to decide which is the correct quantity, the concepts of TPM will simply be collected into three different groupings of these concepts: Autonomous Maintenance, Planned Maintenance, and Maintenance Reduction.

Autonomous Maintenance

The central idea of autonomous maintenance is using the equipment operators to perform some of the routine maintenance tasks. These tasks include the daily cleaning, inspecting, tightening, and lubricating that the equipment requires. Since the operators are more familiar with their equipment than anybody else, they are able to quickly notice any anomalies. The training required to make autonomous maintenance effective comes in several forms: the manufacturing and maintenance staff and their management are educated on the concepts of TPM and the benefits of autonomous maintenance, the maintenance staff trains the operators on how to properly clean and lubricate the equipment, and special safety awareness training is provided to address the new tasks performed by the equipment operators.

Implementing autonomous maintenance often includes the use of 'visual controls'. Visual control is an approach used to minimize the training required to learn new tasks, as well as to simplify inspection tasks. The equipment is marked and labeled to make

[21] "Introduction to TPM Training", Westcott Communications, Inc.

identification of normal vs. abnormal conditions easier to identify. For example, the face of a gauge will be colored to show the normal operating range, lubrication points will be color coded to match the container that stores the proper lubricant, bolts will be match-marked with the surrounding structure so any movement is obvious. All of these inspections are also documented on simple check sheets that include a map of the area and the appropriate inspection route.

The equipment operators are also expected to collect daily information on the health of their equipment: downtime (planned and unplanned), product quality (preferably SPC data, rather than just reject rates), any maintenance that was performed (tightening loose bolts, adding coolant fluid, etc.). This information is useful to both the operator and the maintenance staff to identify any signs that the equipment is beginning to degrade, and may be in need of more significant maintenance. Additional data collection requirements are discussed in the TPM Metrics section, later in this chapter.

Even though autonomous maintenance is supposed to be implemented in a supportive environment, using a cross functional team approach, there are a few common concerns that need to be addressed. First, the equipment operators are now being asked to assume additional responsibilities. These new tasks must be treated as a priority by management, and the operator's performance measures should be modified to include these new activities. Second, the maintenance staff is being asked to give up part of their responsibilities. This can cause the maintenance staff to worry about their job security, especially if the company is currently down-sizing. To address these fears, management must communicate their support for the new maintenance approach, and provide the opportunity for the maintenance staff to assume new responsibilities. Ideally, the maintenance staff will now be free from their daily fire-fighting activities, and can focus on planned maintenance, equipment analysis, and equipment design activities. Third, these changes in roles and responsibilities need to be developed with union representative involvement. In some instances, union contracts may have stipulations that constrain, or encourage these changing roles.

Planned Maintenance

By removing some of the routine maintenance tasks through autonomous maintenance, the maintenance staff can start working on proactive equipment maintenance. Planned maintenance activities (also known as 'preventive maintenance') are scheduled to repair equipment and replace components before they breakdown. This requires the production schedule to accommodate planned downtime to perform equipment repairs, and allowing these repairs to be treated as a priority on par with running the equipment to produce parts. The prevailing theory is that as the planned maintenance goes up, the unplanned maintenance (breakdowns) goes down, and the total maintenance costs go down as a result. The following graph shows this theoretical trade-off curve.

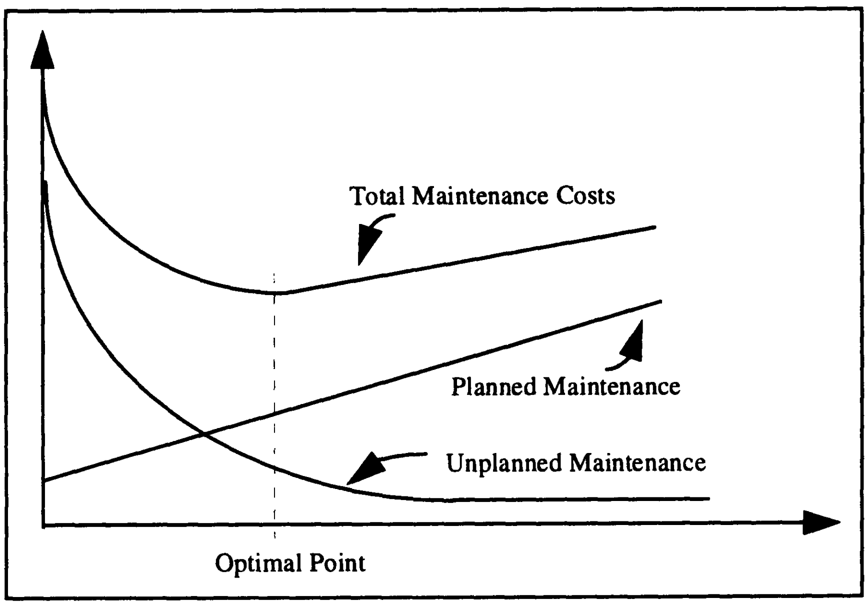

Figure 7: Trade-off Between Planned and Unplanned Maintenance

However, most of the TPM programs that I have witnessed have failed to collect the necessary data to prove this theory. Even if this trade-off is not always achievable, it is easy to see that the equipment will likely receive better care than it was prior to implementing TPM. The manufacturing and maintenance organizations, as a team, should determine the proper amount of planned maintenance, based on the health of the equipment and the type of manufacturing process. Performing excessive amounts of maintenance can be as costly as not performing enough maintenance; their needs to be a balance point determined by careful analysis of the equipment.

Performing planned maintenance, in the proper amounts, requires an in-depth understanding of the production equipment, down to the equipment component level. This understanding needs to start with the products and their critical features, and flow down through the equipment, the equipment's processes, to the process parameters. The following figure shows a graphic example of how the critical top level requirements (key characteristics) of a product can be traced down to the manufacturing process parameters.[22]

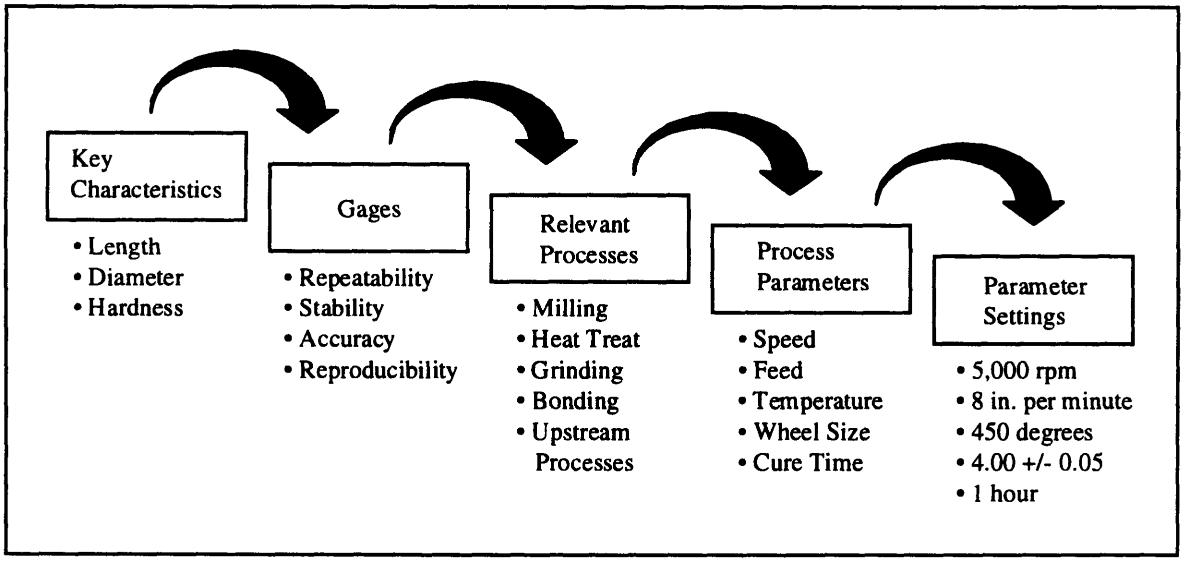

Figure 8: Key Characteristic Flowdown to Process Parameters

Once the manufacturing and maintenance team has identified what they believe to be the critical process parameters, they need to validate these, as well as determine the proper parameter settings. The best way to accomplish this is through Designed Experiments (a.k.a. DOE). These designed experiments will identify which of these process parameters provide the greatest amount of leverage for improving the equipment performance that is linked to the critical product features.

---

[22] "Hardware Variability Control, Designing and Building for Advanced Quality", Boeing Documentation, 1994.

Planned maintenance uses data from process capability and machine capability studies to determine acceptable performance levels. The process capability studies evaluate the equipment's ability to manufacture consistently high quality parts. The machine capability studies analyze the equipment's ability to perform a specific set of operations, and compares the results to industry standards. Both of these studies, when performed on a periodic basis, can provide indicators that the equipment's performance is going downhill, and that it will start producing bad parts, or have a breakdown, in the near future. This data can also be stored in a maintenance data base so that similar equipment, or similar equipment components, can be analyzed together to look for chronic problems. Carefully combining the data in this way can help reduce the problems from making decisions with insufficient data.

Maintenance Reduction

The final TPM concept is really made up of two concepts, equipment design and predictive maintenance, that are focused on reducing the overall amount of maintenance that is required. By working with equipment suppliers, the knowledge that is gained from maintaining equipment can be incorporated into the next generation of equipment designs. This 'Design for Maintenance' approach results in equipment that is easier to maintain (easy to reach lubrication points, access covers to inspection points, etc.) and can be immediately supported with autonomous maintenance. The equipment manufacturer can even include the visual control markings and labels that the customer currently uses for cleaning, inspecting, and lubricating. This communication between supplier and customer can also be used to establish equipment performance criteria. Both the supplier and the customer should be able to achieve the same results from their machine capability studies, and this can serve as an equipment acceptance test. Also, the equipment supplier may be able to provide data on their components that will help to determine the required frequency of inspections and planned maintenance.

The other method of reducing the amount of required maintenance is to perform special equipment analysis to collect data that can be used to predict equipment failures. This type of analysis includes thermography, ultrasound, and vibration analysis, which allows a technician to gather information on what is happening inside the equipment. Thermography is used to detect equipment 'hot spots', where the excessive heat may be related to bearing wear, poor lubrication, or plugged coolant lines. Ultrasound analysis is used to detect minute cracks in the equipment that are invisible to the human eye. If these cracks are detected early enough, repairs can be made before a catastrophic failure occurs. Vibration analysis is used to detect unusual equipment vibration (both in magnitude and frequency). Well performing equipment will have a certain vibration 'signature', and any changes in this signature can be an indication that internal components are wearing out or coming loose. These types of equipment analysis can be performed on a periodic basis, the frequency of which can be fine tuned as historical data starts to show trends. These studies are also useful for finding the causes of chronic problems that can not be eliminated with the data collected by the operator's inspections and the regular planned maintenance.

3.3 Equipment Effectiveness

"When people use the term 'equipment effectiveness' they are often referring only to the equipment *availability* or up-time, the percentage of time it is up and operating. But the overall, or true effectiveness of equipment also depends upon its performance and its rate of quality".[23] One of the primary goals of TPM is to maximize equipment effectiveness by reducing the waste in the manufacturing process. The three factors that determine equipment effectiveness: equipment availability, performance efficiency, and quality rate are also used to calculate the equipment's Overall Equipment Effectiveness (OEE) measure which is described later in the TPM Metrics section.

Equipment Availability

A well functioning manufacturing system will have the production equipment available for use whenever it is needed. This doesn't mean that the equipment must <u>always be</u> available. For example, in a synchronized production system there is little benefit to having equipment up and running when the products aren't necessary. This simply builds up the

[23] "Introduction to TPM Training", Westcott Communications, Inc.

system's inventory. However, if there is a need to increase the production rate, the equipment must be capable of satisfying the increased demand. The equipment management program must strike a balance between the cost of keeping the potential utilization of the equipment high, versus the cost storing excessive inventory to avoid missing a sales opportunity.

The equipment availability is affected by both scheduled and unscheduled downtime. In a well functioning system the unplanned downtime is minimized, while the planned downtime is optimized; based on the amount of inventory in the system and the equipment's ability to change production rates. The in-process inventory can often be used to satisfy the downstream demands while the equipment is temporarily shut down to perform maintenance tasks. Determining the proper amount of inventory becomes a function of how often the equipment is down for both scheduled and unscheduled repairs.

The most common cause of lost equipment availability is unexpected breakdowns. These failures affect the maintenance staff (which must scramble to get the equipment running) and the equipment operator (who often has to wait for the equipment to be repaired to continue working). Keeping back-up systems available is one way to minimize the effect of lost equipment availability. However, this is rarely the most cost effective approach since it require investing in capital equipment that wouldn't be need if the equipment performed more reliably. Another drain on the equipment availability is the time required to change-over the equipment to run different products. This 'set-up' time is often overlooked, even though it has the potential to eliminate a significant amount of non-value added time in the production cycle.

Performance Efficiency

Equipment efficiency is a commonly used to metric when evaluating a manufacturing system. The efficiency is typically maximized by running the equipment at its highest speed, for as long as possible, to increase the product throughput. The efficiency is reduced by time spent with the equipment idling (waiting for parts to load), time lost due to minor stops (to make small adjustments to the equipment), and lower throughput from running the equipment at a reduced speed. These efficiency losses can be the result of low operator skill, worn equipment, or poorly designed manufacturing systems.

However, just measuring the equipment's efficiency can lead to poor decision making, because the manufacturing system may not benefit from traditional goal of 100% efficiency. The important criteria is how many parts should the equipment be producing, not how many can it produce if run at a break-neck pace. The target efficiency needs to consider how many parts the equipment is designed to produce, and how many parts are needed to satisfy the downstream requirements. When the equipment is up and running, it should be capable of being run at its designed speed. But when the parts aren't needed, shut the equipment down and use this time to perform other tasks, rather than slow the equipment down to reduce the throughput. This occasional downtime can be very useful for performing autonomous maintenance, planned maintenance, and equipment analysis.

Quality Rate

If the equipment is available and operating at its designed speed, but is producing poor quality parts, what has really been accomplished? The purpose of the manufacturing system is not to run equipment just to keep people busy and watch machines operate; the purpose is to make useful products. If the equipment is worn to the point where it can no longer produce acceptable parts, the best thing to do is shut it down to conserve the energy and raw materials, and repair it. Quality losses also include the lost time, effort, and parts that result from long warm up periods or waiting for other process parameters to stabilize. For example, the time lost and parts scrapped while waiting for an injection molding machine to heat up should be considered part of the equipment's quality rate.

The effort to improve the quality rate needs to be linked back to the critical product requirements. There is little benefit from producing parts that are perfect in almost every feature, except for the critical feature that matters most to the customer. Once again, the concept of key characteristics is useful for aligning the critical product features with the responsible equipment parameters. These are the parameters that need to be improved in order to have the maximum benefit to the overall system. These are also the parameters and features that should be measured when determining the quality rate of the equipment.

3.4 TPM Feasibility

Practically every book written on the subject of TPM will have a section dedicated to describing the benefits, some of which list examples of companies that have achieved monumental gains from their TPM efforts. The most commonly listed benefits of TPM include the following.

- Reduced Variability (of production parts and production schedules): This results from equipment that has greater accuracy and repeatability, and from less unexpected breakdowns.
- Increased Productivity: Since the equipment is breaking down less frequently, the machines and operators are not waiting around while it gets repaired. Also, there is more throughput due to less total downtime, reduced set-up times, and fewer equipment adjustments.
- Reduced Maintenance Costs: With less 'fire-fighting' required, the maintenance staff can level load the maintenance work orders. Also, the equipment is repaired on an as needed basis, rather than a just in case basis; so unnecessary replacement of components is reduced.
- Reduced Inventory: The manufacturing system doesn't need to store as much in-process inventory to provide a protective cushion to protect against starving the downstream process when equipment breaks down excessively. Also, the equipment spare parts inventory can be reduced, based on more accurate estimates of component replacement requirements.
- Improved Safety: Operators are more familiar with their equipment due to the daily inspections and minor maintenance performed. Further, there are less breakdowns that require removing jammed parts, broken chains, etc.
- Higher Morale: Many operators are more satisfied with their jobs, due to the increased ownership and responsibility that comes with autonomous maintenance. Additionally, the maintenance staff is relieved of the 'tedious' inspection tasks that used to fill their days. Both of these organizations get to develop new skills to support the TPM concepts.

But, the TPM literature often treats TPM as the manufacturing system, and fails to recognize the other elements of a well functioning manufacturing system. Topics such as production scheduling to eliminate excess inventory, using flexible tooling and systems to allow rapid response to market changes are typically ignored. Most TPM implementation plans fail to start with the first and most important question: *Does TPM make sense for this manufacturing system?* Determining the answer to this question requires an evaluation of the system's labor costs to identify it's 'Achilles' heel'.

In the case of continuous flow manufacturing processes, TPM will likely provide significant benefits. A manufacturing system that uses a synchronized production schedule with little, or no, work in process inventory will likely provide a fertile ground for TPM benefits. Also, a manufacturing system that makes extensive use of automation, or semi-automation, with little human intervention would also be likely to benefit from TPM. In these examples, if the equipment is currently experiencing high rates of unplanned maintenance, and the maintenance staff does not have reliable data collection methods, the benefits from TPM could be quite large.

If the manufacturing system in question is composed largely of small job shops with primarily hand-work operations, TPM may not provide sufficient benefits to offset the cost of training everyone and implementing data collection systems. Also, if the production rate is extremely slow, where there is ample time to repair the equipment before the rest of the production line is affected, highly reliable equipment may not provide significant economic gains. In these examples, time and effort may be better spent on identifying and controlling the sources of hardware variability related to the critical component features, or reducing the in-process inventory to identify the production bottlenecks. However if the labor costs are high in these plants, the cost of lost productivity (due to downtime) may drive manufacturing costs so high that a TPM program becomes cost effective.

In the ten step process implementation methodology provided in Appendix A, the second step is 'Identify the Process to Improve'. The team that is working to improve or implement new processes needs to start with an objective look at their manufacturing system and decide if TPM, or some other process, is the best place to start. This analysis may reveal that the manufacturing process is not yet ready to implement TPM. Perhaps there is more basic housekeeping that is first required, or that more information is needed on the current processes to even know where to start. Additionally, if the current manufacturing system has excess capacity, TPM may not yield many immediate benefits. However, if demand increases and additional capacity is required, it may be too late to start a TPM program and get the additional capacity through improved equipment effectiveness.

To determine if the manufacturing system is ripe for TPM, start by collecting some data on the current situation. The following graph shows a sample of the data that may be collected on the sources of hardware variability.[24] Since equipment performance has an effect on the resulting products, this provides a good starting point.

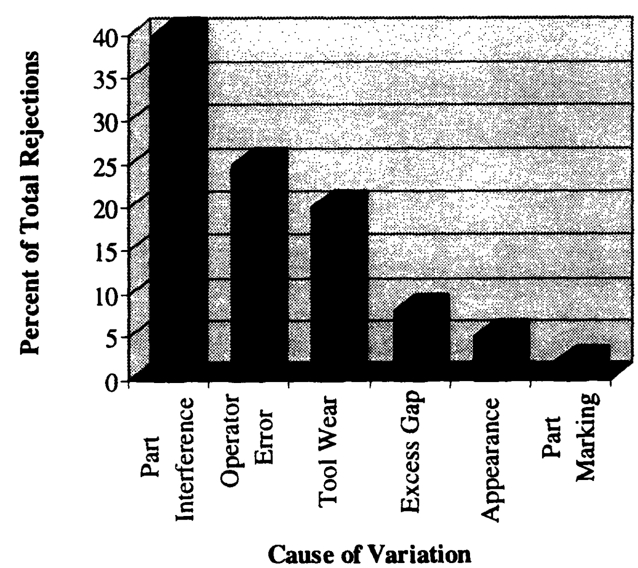

Figure 9: Causes of Hardware Variability

The largest cause of hardware variability in Figure 8, "Part Interference" may be due to equipment variation, but it may also be due to poor design practices where tolerances have been allowed to accumulate. The second largest cause, "Operator Error" will probably not see much effect from implementing a TPM program. But, the third cause, "Tool Wear" could easily be directly related to equipment maintenance practices. In this example, the next step that the team would need to take would be to collect some more information on

---

[24] "Key Characteristics, The First Step to Advanced Quality", Boeing Documentation, 1992.

the root causes of the part interference problem. If it turned out that equipment performance was a large contributor; starting a TPM program may help address two of the top three causes of hardware variability.

The bottom line to the idea of TPM feasibility and finding the answer to the question of: Does TPM make sense; is the simple answer: "It depends". There are many situations that can benefit from TPM, but there are also many situations that would only see modest results. Rarely is TPM the first process that the manufacturing organization needs to implement to improve their operations. The improvement activities need to start with a careful determination of the critical customer requirements, and then move on to evaluating the existing system's ability to satisfy those requirements. The organization needs to estimate the benefits and effort required to implement TPM and compare this with other improvement opportunities such as employee skill training, rudimentary housekeeping, or organizing the manufacturing system to streamline product flow.

Also, the organization needs to balance the costs and benefits of TPM against the cost of living with the existing situation: excess inventory between manufacturing steps, maintenance staff constantly fighting breakdowns, schedule disruptions, poor quality parts, etc. Attacking all of these problems will require a focused and long term commitment, and eliminating all of them may not be cost effective. It may make more sense to store a little extra inventory rather than spend the money required to totally eliminate all breakdowns.

3.5 TPM Metrics

As documented in the previous section, there are data collection requirements that are a prerequisite to even starting a TPM program. Once the organization has decided that TPM is appropriate for their current situation, there are additional data collection requirements inherent in TPM.

Overall Equipment Effectiveness

The concept of overall equipment effectiveness (OEE) is included in nearly all TPM literature, and is described in detail in Appendix B (for those interested in learning how it is measured and used). OEE is calculated by multiplying the equipment availability, performance efficiency, and quality rate; which were previously described. The data required to determine these values is: scheduled downtime, unscheduled downtime, and throughput (both good and bad parts); which is collected by the equipment operators on a daily basis. Implementing control charts on the equipment availability, performance efficiency, and quality rate provides aggregate data that is useful for tracking any changes in equipment performance. However, these control charts should have pre-defined thresholds to determine when more detailed data collection is required, so that the necessary changes can be made prior to catastrophic failure. Determining these thresholds requires first collecting a history of the OEE data, along with a history of more detailed data, where undesirable events and their causes can be identified.

OEE gives a useful yardstick for tracking the progress and improvements from the TPM program; but it does not give enough detail to determine why the equipment is better or worse. For example, OEE will reflect a drop in product quality, but it will tell you nothing about why quality is suffering, or what can be done to resolve the problem. To determine the cause of the observed events, supplemental data is required.

Supplemental Data Collection

The data collection methods documented here are not described in the TPM literature, but can be found in process control and capability literature. These supplemental data are intended to be more useful for problem solving and decision making than the aggregate measure of OEE.

Statistical Process Control (SPC) data, collected on the critical features of the products, can provide feedback to equipment operators on the repeatability of specific equipment operations. If the process goes out of control, the SPC data should immediately relay this information to the operator.

SPC data collected by monitoring the equipment itself, is one step closer to true in-process data collection. For example, a strain gauge may be mounted to a milling machine's spindle. As the cutter wears, more force is required to maintain the established speed and feed rates which is recorded by this strain gauge. Historical data on strain readings and correlated part quality can be used to determine thresholds that define the allowable wear before the cutter needs to be replaced. This approach differs from the previously described predictive maintenance; this is continuous monitoring and predictive maintenance is only performed periodically.

Collecting SPC data on critical process parameters such as feed, speed, temperature, time, etc. is another step closer to measuring the underlying process. This approach requires first identifying the critical process parameters (those that affect the critical product features), then determining their optimal settings. This can be accomplished using DOE techniques, and the resulting data is also useful for determining the Planned Maintenance requirements described earlier in this chapter. Once the critical parameters are established, the operators can collect data or use continuos monitoring to track the parameter's performance.

For SPC analysis on equipment and process parameters, special 'short run' methods may be required due to limited data quantities. Also, an effective method for monitoring these parameters is the "Western Electric Rules" for control charts.[25] These rules state that a process is to be considered out of control when any of the following are detected in the control charts:

- One point is more than three standard deviations from the process mean
- Two out of three points are at least two standard deviations from the process mean
- Four out of five points are at least one standard deviation from the process mean
- Eight points in a row lie on the same side of the process mean

The on-going measurement of the process must strike a balance between providing data that is too aggregated to be useful, and providing so much data that nobody has time to analyze it. If the data can not be easily monitored, the burden of analysis can outweigh the benefits that come from the analysis.

3.6 TPM Implementation

Since there are detailed examples of TPM implementation plans contained in both Appendix B and Appendix C, the following description of TPM implementation provides

[25] "Advanced Quality System Training, Variation, Control, and Capability", Boeing Documentation, 1991.

only an overview of the critical issues that should be considered. The following chart depicts the principal activities that make up the majority of the TPM implementation effort. This implementation plan uses the TPM Concepts that were described at the beginning of this chapter, and should be given "approximately 3-5 years to be completed"[26].

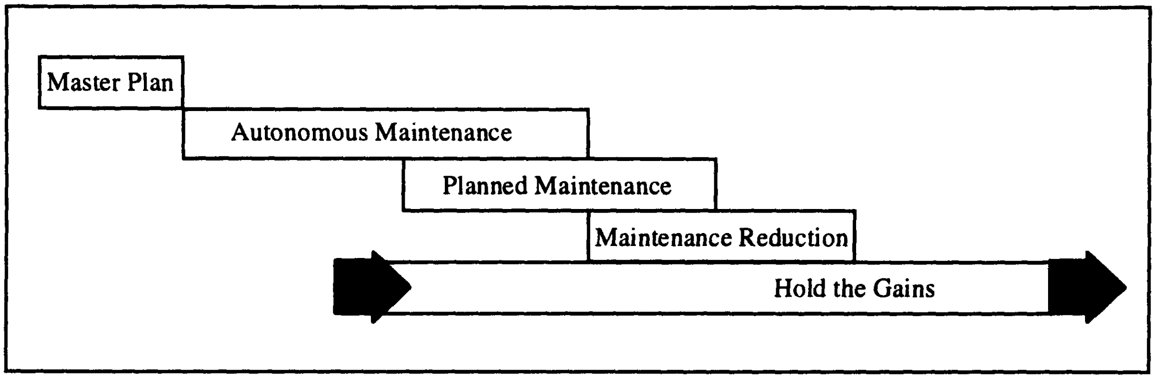

Figure 10: TPM Implementation Activities

The following is a brief description of each of the TPM implementation activities:

Master Plan:

The TPM team[27], along with manufacturing and maintenance management, and union representatives determines the scope/focus of the TPM program. The selected equipment, and their implementation sequence are determined at this point. Baseline performance data is collected and the program's goals are established.

Autonomous Maintenance:

The TPM team is trained in the methods and tools of TPM and visual controls. The equipment operators assume responsibility for cleaning and inspecting their equipment and performing basic maintenance tasks. The maintenance staff trains the operators on how to perform the routine maintenance, and all are involved in developing safety procedures. The

---

[26] Nakajima, Seiichi, "Introduction to Total Productive Maintenance", Cambridge, MA, Productivity Press, 1984.

[27] The TPM team should be composed of the following: the affected equipment operator, maintenance mechanic/technician, process engineer, industrial engineer/scheduler, equipment/tool design engineer, manufacturing engineer/production planner, and quality assurance representative.

equipment operators start collecting data to determine equipment performance (see previous TPM Metrics section).

Planned Maintenance:

The maintenance staff collects and analyzes data to determine usage/need based maintenance requirements. A system for tracking equipment performance metrics and maintenance activities is created (if one is not currently available). Also, the maintenance schedules are integrated into the production schedule to avoid schedule conflicts.

Maintenance Reduction:

The data that has been collected and the lessons learned from the TPM implementation are shared with equipment suppliers. This 'Design for Maintenance' knowledge is incorporated into the next generation of equipment designs. The maintenance staff also develops plans and schedules for performing periodic equipment analysis (thermography, oil analysis, etc.). This analysis data is also fed into the maintenance database to develop accurate estimates of equipment performance and repair requirements. These estimates are used to develop spare part inventory policies and proactive replacement schedules.

Holding the Gains:

The new TPM practices are incorporated into the organization's standard operating procedures. These new methods and data collection activities should be integrated with the other elements of the production system to avoid redundant or conflicting requirements. The new equipment management methods should also be continuously improved to simplify the tasks and minimize the effort required to sustain the TPM program.

3.7 Summary

Total Productive Maintenance is a world class approach to equipment management that involves everyone, working to increase equipment effectiveness. Successful implementation requires shared responsibilities, full employee involvement, and natural work groups. A simple analogy to describe the TPM approach is to consider the activities of the average car owner. The owner (equipment operator) performs minor maintenance activities such as checking the oil, checking the air in the tires, perhaps even giving the car a tune up. However, if something major goes wrong, an expert auto mechanic (maintenance technician) is called in to perform the difficult tasks. The important distinction between this car analogy and production equipment, is that most traditional organizations treat their equipment as if it were a rental car.

TPM is often implemented as a stand alone improvement activity. However, it is my belief that it should be done in concert with the other elements of a world class manufacturing system. The synergy of the world class manufacturing concepts such as inventory reduction, hardware variability control, and cycle time reduction, can provide benefits that are greater than the sum of their parts. I would like to close this chapter with an old proverb that was shared with me: "Production equipment is like the goose that lays the golden eggs. If you want to keep getting golden eggs, you need to take care of the goose!".

4. Analysis of Existing TPM Activities

Total Productive Maintenance is nothing new to the Boeing Commercial Airplane Group. Several different manufacturing organizations have been working on their TPM plans for nearly five years, and internally developed training material has been around for almost as long. This chapter analyzes a handful of the on-going TPM implementation efforts to gain additional insight into what creates a successful TPM program. The common issues that each organization has faced, the barriers that they have encountered, and the factors that have enabled their successes are provided. Also, a brief list of recommendations that could eliminate some of these barriers, and enhance their programs are provided.

4.1 Sample of TPM Projects

The following is an analysis of four different TPM projects that are currently active at BCAG. The analysis started out by reviewing the current status of TPM activities at the primary research location. Additional facilities were then evaluated to gain insight into what is working and what is not working elsewhere in the aircraft manufacturing environment, where the production rates are relatively slow. Most TPM literature only documents the star performers, and doesn't describe the challenges and failures that often reveal the deeper lessons. By benchmarking these other facilities, their experiences could be used to determine the actions necessary to improve the 757 fuselage assembly TPM plans.

The analysis consists of a description of each manufacturing facility, the scope of each TPM program, the data collection methods, and the results achieved by each facility. The intent of these analysis is not to completely evaluate all aspects of each manufacturing system, but to analyze the TPM activities to get descriptive data on the manufacturing processes that TPM exists within. This is by no means a comprehensive listing of the TPM activities currently taking place within BCAG; it is merely a representative cross section, based on personal observations, interviews, and the results of a brief survey.

Site #1: Utilizing Advanced Technology Equipment

This facility is included in the analysis because it served as the primary location for my research activities. analyzing this area would provide me with an understanding of their current TPM efforts and give me the opportunity to learn about their manufacturing processes. This particular site received the most thorough evaluation, since the majority of my time was spent in this area.

Product Mix/Volume

This production facility manufactures fuselage panel assemblies, composed of large components (up to approximately 10' X 20' sheets of aluminum). They make approximately 20 different assembly configurations, some of which have unique customer requirements. However, most of the products are based on small variations from only a few relatively stable configurations. Each assembly takes about three to five days to flow through the necessary assembly steps. Sub-components that are manufactured in this area may be produced in single units, or in batches, where batch sizes range from only a few parts up to approximately 20 parts. Overall, the production rate is relatively slow with major products moving to the next station every few days. The schedule in this area does not change very often. This far into the overall aircraft assembly, the schedules are quite rigid to avoid disrupting the final assembly and customer delivery schedules.

Manufacturing Process/Equipment Technology

This facility is organized into about ten separate manufacturing cells. Each cell is basically organized around a particular piece of production equipment and the associated manufacturing process. The different cells use a wide variety of equipment; from large automated trimming and drilling machines, to simple hand-held rivet squeezers. The products flow through the area following a fairly standard path. However, some assemblies require a different flow that only uses a portion of the typical equipment, and then goes through specialized tooling (such as an aircraft requiring a large freighter door). A small portion of the equipment is shared by several cells; such as the small tools and rework areas. The various cells typically locate and drill fastener holes, temporarily attach the parts, and then send the assembly through one of the large semi-automated riveting machines (see Chapter 2 for details on the assembly process). The recently purchased production equipment includes a significant amount of automation, and have been configured to produce a variety of assembly configurations. One of these new machines is now the pacing item for the overall fuselage assembly throughput, since each fuselage assembly has components that are produced on this machine. The overall manufacturing system in this facility is not quite an assembly line, but is fairly close, with a particular sequence of operations that the majority of the assemblies follow.

TPM Leadership

Approximately one year before this research, TPM was listed as one of the 'strategic initiatives' by the vice president of the parent division. At that time, several groups started using some of the BCAG developed TPM training material to get several TPM projects started. Then, about six months prior to my arrival, the vice president removed TPM from the division's initiatives. At that time virtually all TPM activities stopped except for a couple of isolated pockets. One individual from the training organization kept TPM alive by getting a couple of the work cell's equipment operators to start developing check lists for equipment inspections. These projects began struggling, due to a lack of overall direction and not being seen as a priority to upper management. The projects struggled to organize meetings and acquire the necessary resources, because their unofficial leaders had no formal authority. The only observable direction was being provided in the form of TPM training, which was given to several of the equipment operators.

TPM Participants

The operators of the newer equipment were involved in the TPM training, along with representatives from the equipment suppliers. The maintenance mechanics were also involved in the equipment installation, so they were helping to teach the operators the basic cleaning and inspection tasks. Most of the remaining team activities were just the occasional training sessions. Once everybody left the training and went back out to the shop floor, the demands of getting equipment running and parts out the door took over.

Also, the shop union steward was involved in the initial TPM meetings to verify that the training and assignments did not violate the union contracts.

TPM Program Scope/Focus

This particular site did not appear to have an overall master plan for deploying TPM. They usually trained the operators on routine maintenance tasks when a new piece of equipment arrived; but this was not a stated goal. Each of the manufacturing cells were given 30 minutes at the end of their shift to clean the area and the equipment. But if the area had fallen behind schedule, this cleaning time was spent trying to catch up with the production schedule. They were also slowly going through the facility to clean and organize the workplace (5-S implementation to improve housekeeping). However, these activities had no relationship to the TPM activities that were also occurring. One of the managers observed that "most of the work necessary to create a TPM program was occurring within the facility, but nobody was orchestrating it to maximize the results". I happen to agree with this individual's insight.

Data Collection Methods/Metrics

The newly acquired production equipment was evaluated approximately every four to six months via process capability studies. The initial capability study would be performed when the equipment was first installed. This information was maintained by the research and development group to look for performance trends in the new equipment.

The daily equipment checklists that were created for a few of the cells (as part of the initial TPM effort) were filled out and filed on a daily basis. I saw no evidence that these sheets of completed tasks were used for any evaluations or decision making.

The area's quality assurance (QA) organization documented any rejected parts, including the cause of the rejection. This data was not visible in the workplace and had to be extracted from the QA database if it was needed. Also, since a given problem can be described in a variety of ways, there is little data available on chronic problems or trends.

Equipment downtime and maintenance labor data was stored in a central maintenance database. Unfortunately, this database was only used for collecting and storing historical data. As a result there was not a lot of effort put into collecting and entering accurate data, since virtually nobody uses the data for analysis or decision making. The maintenance staff also performed occasional equipment analysis, such as vibration analysis and thermography. These studies were treated as an isolated event and the resulting data was not included in the centralized database.

Resistance Encountered

I did not observe, or even hear of any actual resistance to the TPM activities in this area. The maintenance staff, the union representatives, the equipment operators, and management all approved of the TPM activities. But, nobody was actively making anything happen, except for the few people that didn't have the necessary authority to push the changes forward. It appeared to be more like apathy than resistance. As one equipment operator told me: "I don't mind doing more of the maintenance work, but my performance is measured by keeping overtime low and getting parts out on time. If somebody wants me to start doing maintenance, they had better include that time in my daily schedule. Besides, if the equipment breaks, it's maintenance's problem, and it may actually give me a chance to catch up on other things". I would say that TPM is not considered a high priority by manufacturing or maintenance management, based on my observation that planned maintenance work must be "negotiated" into the production schedule. Also, if the shop falls behind, the production schedule can be revised to eliminate the planned maintenance's schedule window.

Results Achieved

- The area is noticeably cleaner and more organized since they started their housekeeping activities (they have the photographs to prove it), but these accomplishments are not linked to the TPM activities.
- A few of the manufacturing cells have developed inspection checklists. Unfortunately, there is no data available that quantifies any benefits that have been realized.

- The new assembly process has manufactured thousands of parts without scrapping any final products. However, there is no evidence available that shows that the minor TPM activities have had an impact on this achievement.

<u>*Summary*</u>

Although there is no observable resistance to TPM, benefits are unlikely unless somebody takes responsibility and starts driving the necessary changes in this area. By starting the housekeeping activities, they are moving in the proper direction. But, they have a long way to go and still need a plan to get them focusing on the proper priorities. Without reliable data collection, down to the detail levels, the area's management team will not know if changes are making useful improvements or simply wasting resources.

Site #2: Developing the Initial TPM Activities

This site is included in the analysis because it is considered by many to be the birthplace of TPM at BCAG. The BCAG TPM training was developed here about five years ago. Also, the original leader of the TPM effort here met with the local union presidents to get their support for TPM prior to moving forward with any changes. These few acts have helped to smooth the way for nearly all TPM activities at BCAG in the last five years.

<u>*Product Mix/Volume*</u>

This facility makes a large selection of small aircraft components, and most of the work is done in small lots of 5-20 parts. They do virtually no custom manufacturing; most products have been made before and the necessary tooling is available. The product volume is much higher here than at Site #1. This facility ships hundreds of parts per day. The daily schedule and resulting product mix changes with very short notice here. The facility gets dozens of schedule adjustments daily. This is the result of changing requirements at the downstream assembly shops. Parts may be miscounted, lost, rejected at assembly, or an airplane in service may need an emergency spare part. All of these factors can cause a high priority schedule change at this site.

Manufacturing Process/Equipment Technology

This site is separated into manufacturing cells that are based on the product's material type (aluminum vs. steel) and then by the type of operations. The site uses a few automated machines for metal forming, heat treating, and chemical treating. The majority of the work is performed using simple tools and equipment to bend metal, attach components, and weld assemblies. For most of the simple tools and equipment there are back-up tools available in case two operators need it at the same time. However, the newer, more sophisticated equipment rarely has a back-up system.

Most work in done in small batches and the manufacturing process usually includes only 2-3 production steps. For example, raw material will be formed into an angle, have a small bracket attached, and then the assembly is painted. There are virtually no major bottlenecks in the overall facility, since it is almost a pure job shop. However, within a given manufacturing cell there may be a specific tool that gets used for nearly every product that is manufactured in that cell.

TPM Leadership

As I mentioned previously, this site is one of the initial TPM projects at BCAG. TPM was initiated approximately six years ago at this site when a facilities maintenance manager attended a TPM conference and "got religion". This manager was able to convince his peers and superiors, up to the vice president of the parent division, that TPM could provide significant benefits. Once this idea had been agreed to by upper management, this manager rounded up a handful of fellow maintenance workers, some equipment operators, and an employee training specialist. Using information from seminars, consultants, and available literature (primarily Seiichi Nakajima's writings), this small group created an extensive TPM training program. This training material, which took some 5,000 hours to develop, has served as the baseline for virtually all of the subsequent TPM projects within BCAG.

Unfortunately, before the team's plans were completely put into practice, the original team was disbanded due to retirements, transfers, or demands back at their 'real jobs'. A new group of individuals stepped up to assume the leadership role for the deployment of these TPM plans. However, at this same time the parent division was making major cuts in overhead expenses, due to the declining aircraft market.[28] The TPM plans were subsequently scaled back and upper management removed many of the TPM goals from their business plans.

TPM Participants

This new TPM team continued to work on deploying a scaled down version of their implementation plans. They continued to receive support from the immediate manufacturing managers, equipment operators, maintenance mechanics and technicians, and quality assurance. There has been a full time TPM Coordinator overseeing these activities as the team has continued to develop and teach new training material. This facility has created small TPM teams in virtually every manufacturing cell to take responsibility for cleaning their areas and implementing simple inspection and maintenance tasks. The maintenance staff is available for these teams, when necessary, but are not full time members of the small teams. The maintenance staff has remained actively involved in the team that is overseeing the activities throughout this facility.

TPM Program Scope/Focus

The TPM program at this site took a two-pronged approach to implementing TPM. First, they had all of the manufacturing cells clean and organize each of their areas. These housekeeping activities were considered to be a prerequisite to additional TPM activities. The work cells also started using visual control techniques (marking proper gauge settings, labeling correct equipment positions, etc.) to simplify the task of monitoring their areas. The visual controls also reduced the effort required to learn inspection processes, since the proper settings and levels were now obvious. Second, the site's TPM focal and a core team developed a matrix that allowed them to use quantitative and qualitative data to rank the equipment used by the manufacturing cells in priority order for TPM implementation. This matrix was composed of factors such as a safety ratings, availability of back-up equipment, critical nature of the resource (used by many operators), product quality rates, etc. Based

---

[28] See Chapter 1 for a discussion of the changes taking place in the aircraft market at this time.

on this analysis of the existing equipment, a prioritized list was created that established the TPM implementation sequence. Incidentally, the results of this exercise provided some unexpected results. For example, safety was not an influencing factor for most equipment, but the availability of a critical resource had a major impact on the work cell's perceived need for TPM. Using this prioritized list, a master plan was developed to start converting the equipment to TPM methods. The teams at the cell level were then given training on the concepts of TPM and then they started developing and implementing their own detailed plans.

Data Collection Methods/Metrics

This site uses a central database for tracking maintenance data, which is very similar to the database used by site #1. However, this site is much more rigorous about getting accurate and reliable data collected and stored in the system. The data in the database is periodically reviewed to look for trends in equipment performance and maintenance response times. Using this data allows the maintenance staff to identify specific equipment, or categories of equipment, that are experiencing chronic or similar problems.

This facility collects very little data on the actual process performance, or equipment component performance. They don't use any noticeable SPC techniques to monitor products, equipment, or components. The facility has not made any observable effort to associate the results of their TPM efforts with their manufacturing costs. The general mood seems to be that "if nobody is asking for this type of data, why go through the additional effort to collect and analyze it".

Resistance Encountered

This site has had enthusiastic support from the manufacturing manager, maintenance staff, quality assurance, and manufacturing support managers. However, as one follows the chain of command further up the organization, this support starts to weaken. This was demonstrated by the major overhead cuts that nearly killed the TPM activities a few years ago. One of the largest challenges to this site was losing people that were deeply involved in the TPM activities, and this problem is still occurring today. I believe that it is good that management is empowering a few people to lead the TPM implementation; but when these people leave the organization, the momentum nearly stops. Management needs to stay actively involved to support the strategic activities that may not be completed by the current TPM teams.

<u>*Results Achieved*</u>

Obviously, this site has made great advancements in developing the TPM information, training materials, and deployment methods. However, there isn't much 'hard data' available to show how much has been gained by these efforts. When questioning one manager about the observed benefits from implementing TPM, his response was "the employees seem to be happier, we get better results on employee surveys, and we've seen a lot more good improvement ideas lately".

<u>*Summary*</u>

This site showed that not only do you need somebody leading the TPM effort, but that this requires a long term commitment. The site also developed a successful method for determining the implementation priorities for the TPM plans. This method has been copied by several other sites, to avoid trying to solve all their problems at once. Once again, data collection does not seem to focus on detail data, or on determining the costs and benefits of implementing TPM.

Site #3: Focusing on New Equipment

This site is included in the analysis because it is somewhat similar to the primary research site, in that they use quite a lot of complex machinery and they are currently bringing in new production equipment. This site has also developed some interesting techniques for collecting data on their equipment. Although this data collection is not part of their formal TPM plan, I believe that these data collection methods could prove useful for making equipment management decisions.

Product Mix/Volume

This site has an unusual product mix for BCAG: they primarily build one of a kind products. These products may be prototypes, or single unit production tools to be used by other manufacturing shops. Since this facility does primarily custom fabrication, their workload and schedules can vary wildly, and they have virtually no 'standard' products that they build repeatedly. When a work package is accepted by this facility, a schedule is negotiated based on the complexity of the product and the current production workload. This schedule is occasionally re-negotiated if the customer's needs change, or if the facility runs into production problems. The facility typically ships less than 100 complete products per week; with the actual quantity depending on the complexity of the current products.

Manufacturing Process/Equipment Technology

Since this facility produces such a wide variety of products, they also have a significant variety of production equipment and worker skills. The equipment ranges from simple drill presses, to highly sophisticated multi-axis automated milling machines. Also, the age of their equipment is extremely diverse. Some of the equipment is brand new, while some of the machines are over a dozen years old. This site also has sophisticated measuring and test equipment, such as coordinate measuring machines. They use this equipment to inspect their products as well as their manufacturing equipment.

Most of the products manufactured at this facility only visit a few of the dozens of manufacturing cells. The manufacturing cells here are organized around specific equipment and manufacturing processes, similar to the previous two sites. There are several pieces of equipment that are extremely specialized and see very little use; while a handful of other equipment sees high usage rates. Also, the facility has the authority to offload work to other parts of BCAG and outside vendors if they are unable to keep up with their workload.

TPM Leadership

This facility only recently adopted the concepts of TPM. This change in equipment management practices was triggered by a series of new equipment purchases. The managers at this site did not want to see this expensive new equipment fall into the state of disrepair that some of the older equipment had reached. In their search for better maintenance methods, they discovered the work being done at site #2. Since site #2 appeared to be having success using a dedicated TPM Coordinator to oversee and facilitate the TPM projects, this facility used the same approach. Manufacturing management took one of the hourly production workers and appointed him to the post of TPM Coordinator. Using this person with factory floor experience proved to be beneficial when convincing the other equipment operators to assume new responsibilities. The TPM Coordinator was given a great deal of freedom by the management team to use other site's TPM plans, or to develop his own. The resulting plans for this site are based on other site's plans, but with some minor customization to better fit into this particular facility.

TPM Participants

The number of people involved in TPM at this facility is steadily increasing. As new equipment is installed, the operator and support personnel are trained in the concepts of TPM. As these small teams learn about TPM and identify improvement opportunities, they pass this knowledge back to the equipment manufacturers. As a result, the design engineers at the equipment supplier are becoming partially involved in this site's TPM activities. The most recent equipment is being delivered with many of the visual control markers and labels already applied. This makes the transition to autonomous maintenance faster, since the equipment's inspection routines are simplified via the visual control methods.

TPM Program Scope/Focus

As alluded to earlier, this facility had a rather narrowly defined TPM scope. This site used a prioritization matrix similar to the one used by site #2, but they placed a heavy emphasis on their new equipment. They also considered the equipment's safety record, critical nature (no back-up available), quality rate, etc. The underlying goal of their TPM program was to keep their new equipment from degrading, which was considered more important than getting the old equipment back into shape. The facility adopted the philosophy that "the equipment will be in the worst shape of its life, on the day it arrives".

This site did not want to wait for their expensive equipment to start breaking before it got the attention that it deserved.

The downside of this approach is that the existing equipment will receive 'business as usual' treatment until the current wave of new equipment arrivals subsides. At that point the existing equipment would start being converted to TPM methods, based on the results of their original prioritization matrix exercise. By only focusing on a small amount of equipment, this facility may be better postured to move beyond the basic TPM education, autonomous maintenance, and visual controls. For example, they have been able to start working on some preventive maintenance planning, reliability engineering studies, and new equipment design and start-up management issues.[29]

Data Collection Methods/Metrics

This facility has done the most extensive data collection of any of the sites being evaluated. However, the vast majority of this data collection is not part of their TPM program, and the data is not being fully utilized. The centralized quality engineering and manufacturing research and development organizations that support this facility have been doing work in this facility to develop better metrics on equipment performance. Incidentally, these organizations are doing similar studies in several other facilities.

One of these data collection studies involves analyzing a machine's ability to repeatedly perform a set of operations with high accuracy each time. These tests are commonly referred to as 'machine capability studies'. They require the equipment to perform a pre-defined set of operations (such as milling, drilling, grinding, trimming, etc.) on a test block of raw material. This test block is then analyzed according to an industry standard (ASME B5.54-1992). This industry standard establishes performance targets for many different types of manufacturing equipment, including coordinate measuring machines. The quality engineering organization uses this analysis periodically to track equipment performance and establish thresholds for acceptable equipment capability. This process differs slightly from typical *process* capability studies, where multiple production parts are manufactured and

[29] See Appendix B for a detailed description of each of these activities.

then measured. The observed measurements from the parts are then compared to the desired engineering tolerances to determine Cp or Cpk values.

Another area of study taking place at this site is equipment monitoring techniques. Gauges are mounted to the manufacturing equipment to constantly monitor process parameters. An example of this involves mounting a strain gauge on a milling machine's spindle. As the machine's cutter wears, the force required to maintain the same speed and feed rate increases. The strain gauge data is then analyzed and compared to the resulting product's features (such as surface smoothness) to determine the force recorded as the allowable cutter wear threshold was surpassed. Using this knowledge, the strain gauge is monitored during equipment operation (or a warning device is installed) to alert the operator that the cutter has worn to the point where the product's features will soon be compromised.

Resistance Encountered

This particular site encountered very little resistance to their TPM activities. This may be partly due to the fact that the airline customers have started ordering more aircraft and the facility has seen an increase in their workload, and the pressure to cut costs has changed to a focus on maintaining costs. Also, this site has taken a fairly conservative approach to their TPM deployment. As a result, it will likely take them many years to get TPM fully deployed, but they are minimizing the risk of taking a wrong turn my moving slowly and methodically. By using this slower introduction, the TPM program seems to be viewed as less threatening to the affected employees. They don't get overwhelmed with too much change occurring all at one time. Further, this site also took the standard approach of including the site's union representatives in the initial planning activity. This has reaffirmed the commitment to work together with the union, rather than in opposition, when implementing these new practices. Having the support of the union's president, which was addressed by site #2 several years earlier, also helped to avoid conflicts at the lower organizational levels.

Results Achieved

Once again, there is virtually no data available that documents TPM's impact on manufacturing costs. This site believes that they are getting equipment that is easier to maintain, since the supplier is incorporating some of the lessons learned on the new equipment. However, they have not published any data that quantifies these benefits. The work being done on machine capability studies and equipment monitoring has shown savings from fewer unexpected breakdowns and timely replacement of worn parts and tools. However, there has not yet been any return on investment data published on these programs. It appears that the employees feel they are seeing improvements due to their efforts, but they have either elected not to, or are unable to, quantify the results.

Summary

Having a finely focused approach allowed this site to reach the more advanced stages of TPM implementation (e.g. predictive maintenance and equipment design). But this has come at the sacrifice of having to ignore some of their existing equipment management problems. This area has employed some useful methods for collecting process-level data on their equipment. The information available from studying the equipment can help avoid unnecessary maintenance, as well as prevent unexpected breakdowns.

Site #4: Enabling New Manufacturing Methods

This site is included in this analysis because it is extremely similar to the primary research site: they also manufacture major assemblies and have recently acquired several pieces of automated production equipment. Further, this site employed a unique approach for prioritizing their implementation plans, which I believed would be useful for facilities that are trying to accomplish more changes than just implementing TPM.

Product Mix/Volume

This site is nearly identical to site #1; they manufacture about major assemblies each week from several different sub-components. The majority of the work here is 'basic and stable', with an occasional assembly that is different than the majority. However, this facility produces virtually no one of a kind, or unique products. Also, the schedule in this facility is extremely stable and the workload is forecast well into the future.

Manufacturing Process/Equipment Technology

This facility is also organized into a handful of manufacturing cells that are focused on a given set of operations and a few pieces of equipment. The sub-components are drilled in small lots, and some sub-assembly work is performed in batches which are synchronized to satisfy the requirements of one aircraft. Since the overall assembly flows through several common manufacturing cells (similar to site #1), there are multiple locations that could potentially hold up assembly production if a catastrophic failure occurred.

The equipment in this facility is also being systematically replaced with automated equipment. The intent of this replacement plan is to improve product quality and increase the flexibility of the manufacturing cells by eliminating rigid tooling (similar to site #1). In areas where automation is not being incorporated (non-critical assembly operations), the production equipment is being left unchanged. Some of this existing equipment is fairly old, but most of it has been well maintained over the last few years.

TPM Leadership

The TPM program at this facility was supported and actively encouraged by the site's top management team. This support was the result of the interesting chain of events that led to the creation of their TPM team. The facility had decided to make a major investment in new automated assembly equipment, so a team was created to identify issues that could cause the new assembly methods to fail. This team identified one of the primary concerns as "excessive variability in the assembly components and their arrival rates". The team realized that they could not simultaneously attack every source of hardware and schedule variability, so the looked for a metric that could be used to prioritize their work. The team found the Overall Equipment Effectiveness (OEE) measure from the TPM literature. This measure allowed them to analyze product quality, equipment availability, and performance efficiency with one metric. The team developed training materials and simple data collection methods for the equipment operators so that OEE could be calculated for the existing equipment.

TPM Participants

The effort required to collect and analyze the OEE data involved nearly everyone in the site's organizations for almost two years. During this time, many existing problems were uncovered that had to be resolved prior to implementing the automated assembly process (e.g. equipment that was not capable of producing parts that would consistently load into the automated system). Once the initial OEE studies were completed and the new assembly process installed, the TPM program was left in the hands of the individuals that were interested in implementing the TPM concepts other than measuring OEE. At this point, the TPM projects started to look very similar to those observed at site #1: A handful of TPM teams still exist and are working to implement autonomous maintenance and visual controls, but there is no apparent master plan that is guiding and coordinating these activities.

TPM Program Scope/Focus

As described in the TPM Leadership section, this site was using one of the concepts of TPM (OEE measurements) to prioritize their variation reduction activities, rather than to deploy TPM. This site did not seem to have a clearly defined master plan for determining or describing their program's focus. As employees were exposed to TPM as part of the OEE training, some of them picked up other TPM concepts and started to apply them. This site is now in the early stages of incorporating many of the ideas described in lean manufacturing principles (pull production, inventory reduction, cycle time reduction, etc.). Since TPM is commonly considered to be an element of lean manufacturing, this site will likely be addressing TPM again in their future.

Data Collection Methods/Metrics

This site collected a large amount of data to calculate the OEE metrics required for their prioritization project. This site also collected more detailed information when the root cause of a performance problem was particularly difficult to identify. For example, process capability studies were performed to determine the equipment's accuracy and repeatability, and designed experiments were conducted to identify critical parameters and their optimal settings. As part of the new assembly methods, this site elected to incorporate SPC data collection into the responsibilities of the equipment operators. This data has proven to be beneficial to the operators, since they now have the ability to monitor their own equipment's performance, and react quickly to any performance problems. However, collecting SPC data on the finished parts is still not truly in-process data collection. To learn what is happening inside the manufacturing process requires data similar to that provided by the equipment monitoring methods developed by site #3.

Resistance Encountered

The initial activities of determining OEE measures for the equipment, to determine problem areas, was well received by both management and the employees. However, once the new assembly equipment was functioning, most people returned to their old methods of equipment management. It appears that once these people didn't have "their feet to the fire" to make sure that this expensive new manufacturing process didn't fail, the idea of continuing with the other TPM concepts was not a critical issue. This seems to be another example of "resistance through apathy". Although nobody is stopping the TPM activities; there isn't anybody pushing for progress either. Without some stimulus to move the people forward, and develop the necessary plans, the existing TPM programs tend to 'die on the vine', and the available resources are simply allocated to projects that are getting more publicity.

Results Achieved

This site has published extensive data on the manufacturing cost savings associated with their new assembly process, and they give the OEE prioritization approach a lot of credit for helping identify their problem areas. Unfortunately, they have not documented a clear linkage between the OEE measurements and the savings achieved by the new assembly process; nor have they addressed the additional TPM activities that have occurred.

Summary

This site used an interesting approach for their TPM plans: "only use the TPM concepts that make sense". This facility proved that it is possible to benefit from TPM without implementing a comprehensive program. Also, this facility laid some preliminary groundwork on linking equipment performance and hardware/schedule variability. They were able to show that using equipment related metrics can successfully direct attention to problems beyond just the physical condition of the equipment. Unfortunately, this site (along with the other three sites) also left many unanswered questions regarding the true savings that can be achieved through TPM.

TPM Implementation Progress Summary

These four sites have each taken a slightly different approach for developing and implementing their respective TPM programs. Consequently, the deferent sites have made varying degrees of implementation progress, with respect to the three principal TPM concepts described in chapter 3(autonomous maintenance, planned maintenance and maintenance reduction). For example, site #2 has primarily focused on the autonomous maintenance activities and has made limited progress on the planned maintenance and maintenance reduction components of TPM.

Appendix B contains a more detailed description of the three principal TPM concepts, and also describes a TPM implementation plan composed of 15 separate tasks. Each of the four TPM projects were evaluated based on their progress toward completing these 15 implementation tasks in the following chart.

Impl. Task \ Site	Site #1	Site #2	Site #3	Site #4
1. Form Mgmt Team	○	●	●	●
2. Form Plng. Team	⊛	●	●	⊛
3. Form Impl. Team	⊛	●	⊛	⊛
4. Intro. to TPM Training	⊛	●	⊛	⊛
5. Safety Procedures	⊛	●	⊛	⊛
6. Cleaning & Inspecting	○	⊛	⊛	○
7. Visual Controls	○	⊛	○	○
8. Standardize Lubrication		○	○	
9. Process Improvement		○		
10. Finish Auton. Maint.		○		
11. Develop Prev. Maint.	○	○	⊛	○
12. Integrate Schedules				
13. Predictive Maintenance			○	
14. Equipment Design			○	
15. Hold The Gains				

○ = Task started in part of site
⊛ = Task completed in part of site, or task started throughout site
● = Task completed throughout site

Figure 11: TPM Implementation Progress

This chart shows that site #1 has struggled to make significant progress, which may be related to their limited planning efforts. Also, site #2 has done an excellent job of getting the initial activities deployed across their site. However, they appear to have stalled when moving into the planned maintenance and maintenance reduction activities (tasks 11 - 15). This loss of momentum may be related to the reduced support from upper management and the changes in TPM leadership. This chart also reflects the work done at site #3 to address planned maintenance and maintenance reduction (tasks 11 - 14). Site #3 has taken an approach that is more narrowly defined, which has allowed greater progress in specific work cells. The similarity between site #1 and site #4 is also apparent in this chart. Although site #4 put more effort into their up-front planning, they chose to focus on overall equipment effectiveness measures. This limited scope may have prevented site #4 from making additional progress into the other components of TPM.

4.2 Common Barriers Encountered

Each of the TPM programs described above have had their share of challenges and set-backs. Although some of these are specific to one particular site, many of the barriers that have been encountered are common to many of the TPM programs. The following information is a brief description of some of the challenges that affected not only some of the four sites described above, but other TPM programs as well.

Strategic Direction

Possibly the most significant challenge to the success of TPM within BCAG is the lack of strategic direction provided. At this time, each TPM program that is initiated is unique to the organization that decides to implement a TPM program. As a result, each of these organizations must either seek out a previous TPM installation, or start from scratch to create an implementation plan. One of the drawbacks of this situation is that the TPM program tends to be 'owned' by just one or two individuals within the organization. If these individuals leave the group, the TPM program typically experiences a gradual decline in direction and support. The end result of these dissimilar programs is that information, tools, and data can not be shared among all of the separate programs. Also, if BCAG should develop an overall TPM strategy and approach, some of these organizations may be forced to back-track to achieve commonality.

Priority Given to TPM

Most manufacturing cells still view TPM as a <u>maintenance</u> issue, rather than as a <u>manufacturing</u> issue. This observation is backed up by the fact that most of the TPM focals are either maintenance or training personnel. This situation is magnified at BCAG since fact that the maintenance organization is totally separate from the manufacturing organization.

These two groups do not report into the same organization until above the vice president level. As a result, the manufacturing personnel are rarely measured on equipment performance, and the maintenance group is rarely measured on production part quality or cycle time. This separation of maintenance and manufacturing essentially eliminates any incentive for managers of both organizations to pool their resources to achieve a successful TPM program. Evidence of this barrier is provided by the noticeable lack of TPM goals and metrics in business plans and performance plans.

Conflicting Processes

At any given time, nearly every manufacturing cell is working on implementing a handful of new manufacturing process, as well as a couple of process improvement initiatives. This usually creates more work than the organization is capable of handling simultaneously. In the end, some of the projects are successful, some get canceled, and others simply get ignored. Unless all of the activities within the organization are documented and prioritized, adding another process such as TPM will simply force some other project to 'fall off their plate'. No organization has unlimited budget, time, and people to allow them to implement every good idea that comes along. As manufacturing and maintenance managers are expected to implement additional processes, they must develop methods for prioritizing their work load. A major step in this prioritization, that commonly gets overlooked, is an evaluation of the possible process integration that can be achieved. Rather than forcing the processes to compete for resources, several process can be combined into one cohesive process that is implemented over a longer time frame.

Data Availability

Several of the efforts to implement TPM have been thwarted by the lack of reliable data to utilize for planning purposes. The existing data collection methods do not emphasize the benefits that can be achieved by accurately monitoring equipment performance. Without this data, it is very difficult to determine the relationship between equipment performance, product quality, and manufacturing costs. The data that is being collected is often not used for any decision making so the quality of this data is never verified. The end result is that there is some data available, but it may be of poor quality, and is not collected in a manner that allows easy analysis. Without reliable data, the organization can not develop accurate prioritization plans and they can not quantify any of the benefits received from their TPM program.

4.3 Success Factors and Enablers

As can be expected, several of the factors that have led to the successful TPM programs are simply doing the opposite of the barriers. However, there are a few additional activities that seem to be common to the more successful TPM programs. For the purpose of this evaluation, I am defining a successful TPM program as any program that has developed implementation plans, followed those plans through, and realized the expected benefits of their implementation. This does not necessarily mean that these "successful" projects have resulted in major financial savings. Some of these programs had less ambitious goals, yet I perceive them as successful if they met their stated goals.

Management Support

The TPM implementation plans that have been successfully deployed typically had the benefit of an extremely supportive management team. This means that management did more than just *allow* TPM to be implemented, they were actually a part of the driving force behind the implementation. The management activities include rewarding teams for proactive maintenance, revising business plans to include TPM goals, allowing production workers to attend training sessions, and communicating the TPM goals to the entire organization. By having management's full support, the TPM program should not 'die on the vine' if the TPM coordinator transfers to another organization.

Focused Approach

Most of these facilities used a different approach for determining where they could achieve the greatest benefits from their TPM program. Although there may not be one best method for prioritizing the TPM implementation sequence, the important decision is to actually take the time to perform this prioritization. No organization has all the necessary resources to simultaneously solve all of their problems, so they must pick and choose their opportunities to utilize their resources. The organizations that developed a clear master plan for how they would transition to TPM practices have made more progress toward their goals than the organizations that have failed to lay out a focused plan of attack.

Operator Ownership

Although management needs to assume a leadership role in TPM implementation, they must also allow the equipment operators to take a prominent role in the development and implementation of TPM. One of the essential concepts of TPM is encouraging the operators to assume more responsibility and authority for decisions affecting their production equipment. If the operator is detached from the TPM program, it is extremely difficult to get proactive equipment inspection and maintenance. The benefit of having the equipment operator deeply involved is that the person that knows the most about the equipment (the individual that runs the equipment day in and day out) is providing input to the plans. Achieving operator ownership requires early involvement by the equipment operators, so that they can feel a sense of belonging to the TPM implementation team. This enables them to have some of their own blood, sweat, and tears invested in the TPM plans.

Just-In-Time Training

Training that is delivered too early is almost as ineffective as training that is delivered too late. If the affected individuals are trained immediately prior to their 'hands-on' use of their new knowledge, they are given the chance to reinforce their classroom learning by getting direct and immediate feedback. This JIT training approach also reduces the impact of the extensive TPM training required. Since the training is given in small doses over a long period of time, it has less of an impact on the organization's ability to meet their production schedule.

Integrated Processes and Schedules

As mentioned above in the barriers encountered, failing to integrate the various processes levied upon the organization creates many conflicts. However, the element of this integration that often gets overlooked is the scheduling activities. Many organizations use totally isolated scheduling systems for their production schedule and their maintenance schedule. In this situation, every preventive maintenance activity must be scheduled by two organizations reaching a compromise on when to shut the equipment down for maintenance. By integrating all of the entities that require access to the production equipment, the organization can avoid the conflicts that arise over who has the highest priority for the equipment. Groups other than manufacturing and maintenance may also need access to the equipment to perform tests (Quality Assurance), or to run prototype parts (Research and Development).

Union Buy-in

Last, but certainly not least, is the issue of getting the employee's union representatives involved in the TPM implementation planning. The introduction of Autonomous Maintenance almost always involves the migration of responsibilities from maintenance technicians to equipment operators. It is ridiculous to wait until an employee files a grievance with the union to consult with these organizations. The union need not be treated as an adversary in these workplace transformations. History has proven that the union may very well support the concepts of TPM, since the affected employees are developing additional skills that make them more valuable to the company. TPM can effectively be used to create a more multi-skilled workplace, which usually improves employee job security.

4.4 Recommendations for Improvement

The most obvious recommendation for the various TPM activities currently in work is to start using the success factors and enablers previously described in order to overcome the barriers that are also described above. In addition, there are several specific activities that I believe will enable BCAG to achieve even greater success with their TPM programs.

The first course of action is to establish a strategic direction for TPM. This can be accomplished with the help of those that are currently involved in TPM, so that their current methods can be retained. For TPM to be widely accepted, and for the various TPM projects to maximize their collective gains, there should be a top level strategy for TPM that ties in with the BCAG manufacturing strategy. Without upper management's involvement and support in developing this TPM direction, these various teams will continue to suffer from the large variety of 'preferred methods'.

Manufacturing organizations need to start collecting meaningful and reliable data on their equipment performance. Without out this data, future TPM projects can not be prioritized, and the benefits of any TPM achievements will remain undocumented. The data collection activities need to start before any changes are implemented in the workplace. How can an organization know if they are doing any better, if they don't know where they started? Also, this data should be used to prioritize their efforts. If data is not collected up front, the organization may be trying to implement TPM in the wrong areas, or they may be better off improving other aspects of their manufacturing system.

There needs to be more emphasis on communicating the vision, goals, and strategy of the organization with respect to the new process that are being implemented. I believe that much of the concern that exists in most organizations is not based on the fear of change, but on a fear of the unknown. This occurs because management is not effectively communicating the forthcoming changes, the impact of these changes, and the reasons for making the changes. In an information vacuum, the people will start to make up their own information; and if there is no data to dispel these rumors, they will be accepted as the truth.

Incentives and rewards need to be revised to encourage the implementation of TPM. This includes tying the goals of the manufacturing and maintenance organization together to get them to work together in an effort to achieve these goals. Whether the group uses OEE as the common goal, or simply includes equipment breakdowns in the manufacturing goals and product quality in the maintenance goals, there must be an effort to create common targets. Additionally, these incentives need to start rewarding the preferred type of activities. This means that fire-fighting is no longer rewarded, and shutting the equipment down to perform preventive maintenance is rewarded.

Finally, there needs to be an effort to integrate the existing manufacturing system's various processes. With the current approach of creating 'process silos', the employees on the shop floor have no means to prioritize their workload, and choose between conflicting processes. My recommendation for solving this problem is to start by looking at the concepts of Lean Manufacturing. This provides an essential framework where the various manufacturing processes can be compiled and integrated to achieve a synergistic relationship. Unfortunately, this is no simple task, and it will likely take several years to get fully organized. But, if the group doesn't start making these changes now, they will only be that much older when they finally do.

5. Implementing TPM in the Fuselage Assembly Process

Previous chapters have described the fuselage assembly process, provided information on situations where TPM can be beneficial, and discussed lessons learned from analyzing a handful of TPM projects. The TPM Feasibility section of chapter 2 established that TPM is likely to provide benefits in manufacturing systems that utilize process automation, have production bottlenecks, or are attempting to reduce cycle time. This chapter will bring this information together to describe some of the critical issues that should be addressed to successfully implement TPM on the Fuselage Assembly Improvement Team (FAIT) program. Although the information in this chapter is written to support TPM implementation in a specific area, the vast majority of the following information is generally applicable to virtually any team that is working to implement new processes in their area.

5.1 Identifying Opportunities

Although there isn't very much reliable data available on equipment downtime or causes of hardware variability for the equipment used by the FAIT program, there is still some useful information to help determine if FAIT could benefit from TPM. First of all, the FAIT program uses a great deal of automated equipment. This equipment is largely responsible for controlling the quality of the finished products, and any variability in the equipment's capability would have an adverse impact of part quality. For example, a worn spindle shaft or worn out cutting tool, would likely lead to poor quality parts. Also, the new assembly equipment is currently the pacing item for the area's throughput, and there is no back-up equipment to handle overflow, or fill in during any downtime. As a result, improving the reliability, availability, and efficiency of this equipment will allow the FAIT program to react to future increased production rates without having to buy additional equipment.

Another factor that affects the FAIT program's TPM opportunities is the fact that the manufacturing cells have already been through a program to clean and organize the workplace. This housekeeping work makes the implementation of TPM easier, since the initial equipment cleaning has already been accomplished. Additionally, the FAIT program's work cells have been working to reduce the amount of non-value added activities in their manufacturing system. They have been reducing their work-in-process inventory, cycle times, and holding accelerated improvement workshops to simplify their operations. These initiatives should be able to be integrated into the TPM activities without much disruption, since they are all working to streamline the manufacturing system and eliminate waste. Further, some of the data collection efforts for these different improvement programs are likely to be complementary.

The FAIT program management team has proven to be supportive of the TPM ideas, although they have not yet made the issue a high priority. The managers appear to recognize that their equipment is critical to the new Accurate Fuselage Assembly (AFA) process, and that they need an overall plan for sustaining and improving this equipment. Plus, the managers have been educated on the basic concepts of TPM and understand that TPM is a significant part of a well functioning manufacturing system. The maintenance staff has also been involved and supportive of the existing TPM efforts that are struggling along in the area. Unfortunately, the maintenance organization has limited data available to help the TPM efforts, and they are currently struggling themselves to keep up with their backlog of maintenance work orders.

Overall, the FAIT program matches several of the attributes presented in Chapter 2 that describe an area that is ripe for TPM implementation. Also, the organization seems aware of the need to improve and appears willing to make the necessary changes. The only real drawback comes from the lack of data available to quantify the size of their opportunity, and to help establish a clear course of actions to deploy a TPM program. The FAIT program could also benefit from having a strong TPM supporter in a position of authority. This person could establish TPM as a higher priority so that the necessary resources could be allocated to the TPM program.

5.2 Focusing the Implementation

At this point, I will assume that the previous information has proven that the FAIT program makes an acceptable candidate for implementing TPM, and that a TPM team has been formed by FAIT management. This assumption kicks off the next set of activities, to develop a plan for where to best start the TPM implementation. From benchmarking the other TPM sites, I observed that a focused approach to implementing TPM resulted in a smoother transition to the new equipment management practices. However, there is a significant amount of work required to determine this implementation sequence.

Developing a list of the area's manufacturing equipment, prioritized in order of perceived needs, requires a thorough understanding of the manufacturing process. The TPM team needs to know which products are critical to the customer's satisfaction of the overall assembly. Further, the team should understand their products down to the specific critical features, and should also know which manufacturing processes determine these critical features. If the team does not have this in-depth knowledge, they would probably be better off to postpone their TPM implementation until they have determined the linkage between the product's key characteristics and the associated manufacturing process.[30]

Their are a host of options available to the TPM team to determine which equipment needs the extra care that comes from a TPM program. The following describes a small cross section of the methods that have been used by other TPM teams to develop a prioritized list of their equipment.

- Start implementing TPM on new equipment as it is brought into the cell. This prevents any new equipment from being allowed to degrade in the first years of its use.[31] During the times where no new equipment is being introduced, the team can use one of the other prioritization tools to develop a second tier of priorities.
- Start working on the equipment that currently breaks down the most. This approach allows the team to attack the most visible maintenance problem in the cell: excessive fire fighting to keep the equipment running. However this 'squeaky wheel' approach may overlook equipment that doesn't break down, but consistently produces bad parts.

---

[30] See the Planned Maintenance section of Chapter 3 for a description of how the product key characteristics can be flowed down to the critical process parameters.

[31] This approach captures the underlying goal of the prioritization method used by the TPM program analyzed at Site #3 in Chapter 4.

- Start with the equipment that is known to have a lot of chronic problems, based on 'tribal knowledge'. This is usually the equipment that everybody complains about the most. However, the team needs to develop a method to quantify the impact of this poorly performing equipment. After all, the problem may simply be that the operators are inexperienced, and nobody has bothered to effectively train them.
- Start with the equipment that has historically created the greatest safety risk. This information is typically available within the manufacturing cell. Selecting equipment that has been involved in an excessive number of accidents allows the team to realize immediate benefits from their TPM program.
- Start with the equipment that is currently constraining the throughput capability of the manufacturing cell. This approach requires the team to identify the throughput/cycle time of each piece of equipment so that the 'bottleneck' equipment can be accurately identified.
- A combination of the above methods receives my personal vote for the best approach. The team creates a matrix that includes data on breakdowns, accidents, part quality, set-up times, throughput, etc.[32] The team applies a weighting factor to each of these attributes which identifies the factors that are more important. For example, safety concerns are obviously more important to the equipment operators than just reducing the set-up times.

The team can easily get bogged down at this point by trying to collect too much data for the prioritization exercise. It is important to remember that the team will eventually get around to the rest of the equipment in the area (as appropriate, per the 'TPM Feasibility' of each work cell). If performance data on downtime, throughput, accidents, rework, etc. is not readily available do not despair; the team can simply rank the equipment relative to each other on a scale of 1 - 5, based on the team's collective experience. This approach may not be perfectly accurate, but it gives the team an agreed upon starting point, which is probably close enough to the unknown true situation.

---

[32] This is the prioritization method used by the TPM program analyzed at Site #2 in Chapter 4.

The information collection is not restricted to just equipment performance metrics. The organization should also be evaluated for its ability to embrace the concepts of TPM. This requires evaluating existing business plans, manufacturing strategies, and individual performance plans. The objective is to identify additional barriers that must be overcome to successfully implement TPM in the area. This is not an easy task, since most barriers are difficult to see until it is too late to avoid them. However, the team should try to use informal interviews or surveys to get a feel for how well a TPM program may be received.

5.3 Deploying the Plans

In an effort to conserve space and focus on the more critical issues, this section will begin with the assumption that the TPM team has selected their target equipment. Further, for this chapter I have elected to skip past the series of activities required to develop the detailed implementation plans. For the interested reader, Appendix A contains a ten step model which can assist a team as they develop their implementation plans. Also, Appendix C describes a detailed example of the FAIT program's TPM implementation plan. This section contains a collection of factors that have helped other TPM teams implement their TPM plans, which have been slightly modified to make them more applicable to the FAIT program.

Management Support

The results of analyzing other TPM projects pointed out that long-term management commitment is critical to successfully implementing TPM. There will certainly be some amount of disruption during a TPM implementation (due to training requirements, equipment evaluations, various meetings, etc.), and management must help smooth these disruptions and provide a consistent direction. This may require changing incentives to reward new behaviors, and providing additional resources to get the program started. Management should show support whenever possible, including spending time in the manufacturing cells to monitor progress.

Start Small

The TPM program should start as a pilot implementation and be grown from there until it finally encompasses all the appropriate areas. As the program expands, training should be provided just prior to the recipient needing the new knowledge. Making the new tasks as simple as possible and using visual cues to assist learning will also help reduce the training efforts. The TPM team should be composed of only those individuals that are directly and immediately affected by the TPM program. Remember, the goal is to have a focused approach; this also applies to team membership and training.

Collect Data

The data collection efforts need to be one of the first, and one of the last activities in the TPM program. The idea is not to overwhelm the team with data, but to give them useful and reliable information. The team should keep the data collection simple, so that the equipment operators can collect and use their own data without having to severely disrupt their daily schedule. This does not require the creation of complex data collection and analysis systems. Most organizations (maintenance, quality assurance, manufacturing, scheduling, etc.) already have adequate systems that merely need to be used properly and have accurate data recorded. Several of these organizations could also share their databases to avoid collecting and storing redundant data. Good data collection allows the team to monitor progress, make decisions, and make necessary course corrections before its too late.[33]

Integrate

The TPM team should share their experience, tools, data collection methods, etc. with other TPM teams that are following in their footsteps. The existing TPM programs should also develop a forum to document common processes and best practices for everyone to use. Further, the TPM team should work with other 'process improvement' teams to make certain that they are all moving the organization in the same direction (this also requires the

---

[33] For a discussion of data collection methods, see the TPM Metrics section in Chapter 3.

'Management Support' discussed earlier). Unless effort is put into these integration activities, there will inevitably be unnecessary conflicts.

5.4 Evaluating the Results

If the team has been collecting the proper data since their initial activities, determining the results of implementation should be relatively simple. Unfortunately, many projects fail to collect data prior to implementing their changes. Another common mistake is not documenting what additional changes occurred in the area during the program's implementation. Without this documentation, the observed results can be confounded with multiple events that occurred over the same time period

The FAIT program should be able to observe the following changes, if their TPM program is to be considered successful.

- Breakdowns and unscheduled downtime are less frequent and are resolved more quickly.
- Planned maintenance activities are more frequent and are incorporated into the production schedule.
- Accident rates in the manufacturing cells are lowered.
- Equipment set-up and change-over times are reduced.
- Hardware variability is reduced and part quality is improved (less rework and rejections).
- Schedule variability and production delays are reduced (less jobs behind).
- Overall maintenance and manufacturing costs are reduced.

Also, the equipment operators should now be performing more cleaning, inspection, and minor maintenance tasks. Additionally, the maintenance staff should be focusing on planned maintenance tasks and equipment analysis studies, rather than constantly battling an out of control work order backlog.

6. Conclusions and Recommendations

This chapter provides a brief summary of the results of my research within the Boeing Commercial Airplane Group (BCAG). I document the conclusions that can be drawn from the information that was uncovered by analyzing their fuselage assembly methods, and their attempts to implement TPM. I also supply suggestions for further research opportunities that may lead to a deeper understanding of what it takes to successfully implement a TPM program.

6.1 Summary of Research Findings

This thesis has identified several different factors that are driving the need for change at BCAG. First, the marketplace is currently undergoing a change; customers are demanding more value from their aircraft investments. As documented in Chapter 1, this is forcing Boeing to lower production costs while simultaneously improving product quality. Further, Boeing is reducing their product lead time in order to become more flexible and responsive to changes in customer demands.

One of Boeing's major thrusts to improve their competitive position has been the introduction of new manufacturing processes. Chapter 2 describes one of these new processes which is being used to assemble aircraft fuselages. However, introducing this new process has created far reaching changes in various organizations. For example, factory worker skill is being replaced with computer-driven production equipment. This change drastically affects the roles and responsibilities of production employees, as well as those of the production support people.

The increased dependence on the production equipment to reliably and repeatedly manufacture high quality products has created the need for a new approach to equipment management. As documented in Chapter 3, Total Productive Maintenance (TPM) is an effective method for addressing this equipment management challenge. However, TPM should not be implemented as a stand-alone process. It should be integrated with the balance of the production system, and the existing process improvement initiatives. Only through this integration can the proper priorities be developed for deploying the various components of an improved production system. Additionally, new metrics need to be employed that allow the separate manufacturing cells to work toward achieving common goals.

TPM implementation activities can be found throughout the BCAG organizations. However, these various activities are not being carried out as part of an overall TPM strategy. Chapter 4 provides an analysis of a handful of these implementation efforts and evaluates their level of success. Many of the individuals involved in TPM implementation communicate informally to share lessons learned, and give advice. Unfortunately, this does not totally eliminate the duplication of effort, and occasional conflicting approaches that occur down at the working levels.

Implementing new processes, whether it is TPM or any other new process, requires a careful analysis of the overall manufacturing system to determine the likelihood of successful implementation. Chapter 5 describes the critical issues that should be considered when developing and deploying an implementation plan for TPM. These implementation decisions provide the opportunity to analyze the existing manufacturing processes and the organization's ability to benefit from TPM.

6.2 Conclusions From Research

The following conclusions have been compiled from interviews and surveys administered during my research as well as personal observations.. These conclusions provide common themes that appeared in several different organizations that were working to implement TPM within the Boeing Commercial Airplane Group.

Top Down Direction

Successful implementation of any new process benefits from a coordinated approach using pilot implementation, lessons learned, then full-scale deployment. Accomplishing this requires clear direction and priorities from upper management. The goal is to avoid a haphazard implementation approach where each organization can decide if they will implement the new process, and then develop their own unique approach. If this occurs, the organizations can not easily share and transfer knowledge, tools, or procedures.

Integrating Processes

New processes must be integrated with the existing system, and positioned to allow for future process introductions. Establishing stand alone processes will create 'process silos' where each process has to compete with the others. This process competition creates a great deal of confusion within the organization, and makes resource allocation extremely difficult. Metrics and incentives that support more than one process (e.g. machine capability data evaluates both product quality and equipment performance) make the prioritization of improvement activities more obvious.

Data Driven Decisions

There is a noticeable lack of useful data available to the lower levels of many of the BCAG organizations. Further, the data that is available is all too often not effectively utilized by the intended organization. This makes it virtually impossible to drive decision making authority down to these lower levels. The lower level organizations need to develop simple data collection methods to gather information that can immediately be used by the factory floor employees. This includes both qualitative and quantitative data. Also, data collection plans should be established at the very beginning of any improvement activities. These improvement activities need to address data collection prior to implementing any changes in the workplace, so that the results of the change can be quantified later.

Impact on Organizations

Most of the organizations that implement new processes fail to fully identify the required changes in the organization's culture. Part of the implementation planning should be dedicated to explicitly identifying the necessary organizational changes. This includes current and future roles and responsibilities for the individuals affected by the proposed process changes. These changes need to be communicated to the organization, and the appropriate training needs to be provided, to make the process change a smooth transition.

Breaking Down the Barriers

In many organizations, TPM is still treated as a facilities maintenance issue rather than as a manufacturing issue. The solution to this dilemma is to tie these two organizations metrics, goals, and rewards together. For example, the maintenance typically has no goals related to product quality, and the manufacturing organization has no goals related to equipment performance. If both organizations were working to maximize the Overall Equipment Effectiveness, they would be encouraged to work together and support each others needs. Another barrier that needs to be addressed is the basic human reaction to change: we usually don't like change. This is often the result of poor communication and training, which leads to a fear of the unknown; not necessarily a resistance to change.

Effect of Equipment Performance

Teams that have started implementing TPM have quickly realized that equipment performance is critical to reducing manufacturing costs. The equipment variation leads directly to hardware variability, which has repeatedly been proven to increase manufacturing costs. This is due to scrapping parts, reworking parts, and adjusting production schedules to accommodate production delays. This poorly performing equipment is typically countered by increasing coordination activities and storing extra inventory. Also, the unreliable equipment prevents the organization from implementing other manufacturing initiatives such as pull production/JIT scheduling. Previous studies have indicated that on average, BCAG's Overall Equipment Effectiveness is well below 'world class' levels.[34] The benefits of improving the equipment management practices across BCAG have been estimated to be in the hundreds of millions of dollars.

6.3 Additional Research Opportunities

This research has provided an initial exploration into the changing role of production equipment. The results of my research provide insight into the requirement for using TPM to improve equipment performance. However, my research has also created at least as

[34] Facilities Asset Management Organization, TPM Strategy Team Study, May, 1995.

many questions as answers. The following is a description of a few of the topics that would provide useful data to the individuals that are working in the TPM field.

Quantifying the Benefits of TPM

This is still one of the major hurdles facing most people working to implement TPM. There has been little success in isolating a manufacturing cell, or piece of production equipment, applying TPM concepts, and measuring the benefits. The challenge in this comes from the long time-frame required to fully implement TPM, and the difficulty in isolating benefits. In most production environments it is difficult to determine which observed benefits can be attributed to which causes. This would probably require the development of new and creative data collection techniques.

Analyzing and Documenting a TPM Implementation Project

Many people could benefit from the 'lessons learned' from a detailed analysis of what a team experiences as they implement TPM. These lessons could provide insight into the cultural and political changes that result from implementing a new manufacturing process, such as TPM. The researcher could either lead, or simply be a member of the TPM implementation team. The results could be formed into a 'case study' to be shared with other organizations to provide an education on what TPM teams can expect.

Aligning Manufacturing Processes

A study could be performed where all of the initiatives and processes affecting an organization are identified and aligned. The driving force behind each of the initiatives, and the associated metrics, could also be evaluated. This research should result in the alignment and prioritization of all the processes that an organization is trying to utilize. I believe that this would be an eye opening experience for both the researcher, and the host organization. The alignment of all these processes would allow the organization to make better trade-off decisions when determining resource allocation.

Addressing Remaining Sources of Variation

The battle to control hardware variability will probably wage on forever. My research has identified an additional weapon to use in this battle: TPM. However, the existing hardware variability control programs and TPM programs are still overlooking several sources of hardware variability. Research is still required to find simplified data collection methods, and data analysis methods for slow production rates. Data analysis in a data sparse environment is another existing challenge. Very short run SPC techniques and data collection at the process level, that can be generalized across multiple products, is still not clearly understood.

Appendix A: Methodology for Process Implementation

In order to implement any major change, a team must utilize some process for developing their implementation plans and for executing these plans. Unfortunately, many teams do not make this a conscious step in their implementation planning. Rather than select an appropriate set of planning and problem solving tools, they haphazardly utilize a random cross section of familiar tools. This poor selection process can cause a team to wander off track repeatedly in their process development and implementation activities.

A.1 Introduction

The most commonly used process implementation methods at BCAG are the 'Situation - Target - Proposal' (STP) and the 'Seven Quality Control Tools' (7QC). Both of these methods are best suited for reactive problem solving, rather than proactive process development. The STP approach fails to provide a method for selecting the important problems, nor does it provide a feedback loop to make future course corrections. The 7QC tools (Check Sheet, Pareto Diagram, Cause and Effect Diagram, Stratification, Control Chart, Histogram, and Scatter Diagram) are an effective set of tools for problem solving, but they do not provide a framework for how to actually work through a problem.

There is a significant amount of material available on quality improvement tools, and management and planning tools. Many of these tools, such as brainstorming, cause and effect diagrams, affinity diagrams, quality function deployment (QFD), etc. can easily be integrated into the methodology for process implementation described here. In an effort to conserve space and avoid simply repeating the material available in other documents; I would recommend the following books to any reader interested in learning more about these specific tools:

- Brassard, Michael, *The Memory Jogger*, Methuen, MA, Goal/QPC, 1985
- Brassard, Michael, *The Memory Jogger Plus*, Methuen, MA, Goal/QPC, 1989
- Shiba, Shoji, Alan Graham, David Walden, *A New American TQM: Four Practical Revolutions In Management*, Cambridge, MA, Productivity Press, 1993

- Clausing, Don, *Total Quality Development*, New York, NY, ASME Press, 1994

A.2 Ten Steps for Process Implementation

This appendix describes a model which provides a useful 'roadmap' for teams to follow when developing new processes, or solving existing problems. The following model is based on the "Select - Analyze - Measure - Improve - Evaluate" model, developed by the American Society for Training and Development;[34] but has been rearranged to align with the 'situation-target-proposal' approach, and expanded to incorporate the use of several quality improvement tools.

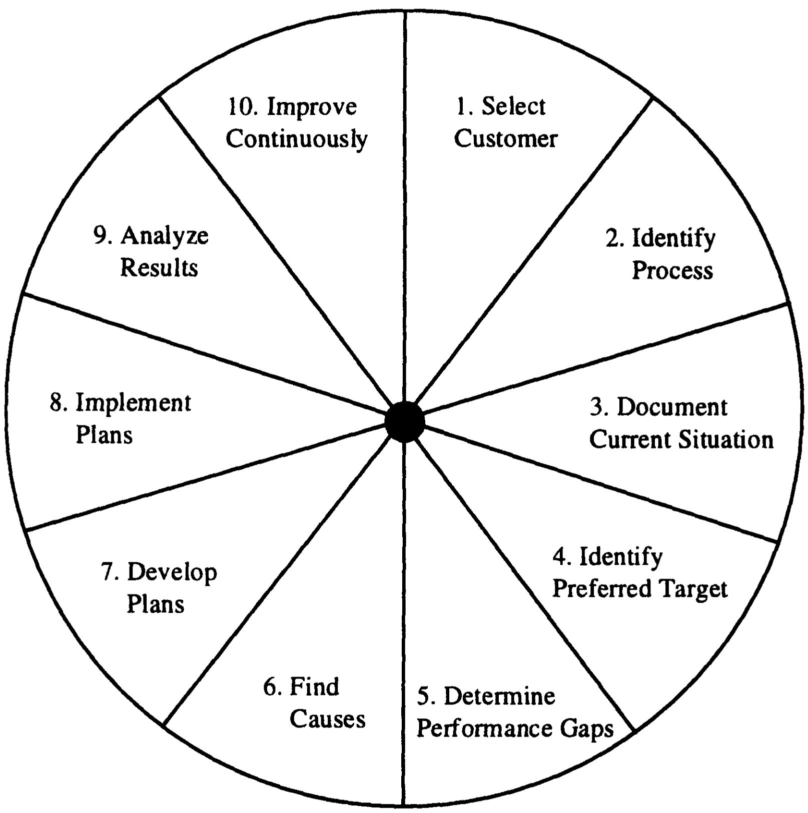

Figure 12: Ten Step Process Implementation Model

The remainder of this appendix will describe the steps in the above model in detail, and conclude with a critique of the model.

[34] Chang, Richard, *Info-Line*, Issue 9210, October, 1992.

Step 1. Select the Customer

If the improvement activity is based on solving an existing problem, the customer will usually be easy to identify, since the customer may actually be responsible for identifying the problem. In the case of proactive improvements, more than one customer can be included in the process. Early involvement of the customer is highly desirable, since the process implementation activity can develop an improved relationship with the customer.

The principal tasks of this step are the following:

1. Form process improvement team
2. Identify the team's customer(s)
3. Conduct customer needs assessment, through customer interviews/surveys
4. Determine critical output requirements

This is one of the most important steps in the implementation planning process. It will establish the initial relationships between the team members. If possible, the team should be cross-functional, with representatives from each of the major organizations involved. However, keeping the team to a reasonable size (5-10 members), must be traded off against having members from every organization

Step 2. Identify Process to Improve

This step is intended to provide a prioritized listing of the processes in need of improvement. If the team is working to address an existing problem, this problem should be compared to other improvement activities currently in work, to ensure that this new problem is a higher priority than existing activities. If the team is addressing proactive improvements, they will more than likely generate several opportunities that are ripe for improvement. These opportunities must be prioritized to allow a focused approach to the implementation planning. After the highest priority process has been improved, the team can then move on to the next highest priority.

The primary functions of this step are the following:

1. List processes which produce an output for the customer(s)
2. Establish process selection criteria and methodology
3. Choose highest priority process needing improvement based on customer requirements

The team may choose from several different methods for determining the process selection criteria. For example, a TPM implementation team within BCAG developed an effective method of prioritizing their implementation efforts by using a prioritization matrix. This TPM team evaluated each process and piece of equipment against several different factors such as safety, bottlenecks, downtime, chronic problems, etc. Each of these factors was 'weighted' based on their perceived importance to the manufacturing process. By ranking the processes and equipment with the weighted factor a prioritized list of processes was created.[35]

This step also provides an opportunity for the members of the team to learn more about their customers. One of the best methods for learning about your customer's needs, is to spend time in their environment. This could include following one of your products through the customer's facilities. The act of becoming familiar with your customer's environment is often referred to as "swimming with the fish".[36]

Step 3. Document the Current Situation

During this step the team works to gain a thorough understanding of the current situation affecting the process in question. In the case of reactive problem solving, they are striving to identify where, when, and how the problem occurs. When working on proactive improvements; the goals are similar; but the focus is at a higher level, on the overall process rather than on a specific problem within the process.

The primary tasks of this step are the following:

1. Define the process boundaries
2. Document the current 'value chain'
3. Flowchart the existing process
4. Identify existing process metrics
5. Identify 'value-added' and 'non-value-added' tasks
6. Evaluate level of awareness regarding the existence of the problem/opportunity

---

[35] Based on the "Prioritization Matrix" developed by the Fabrication Division's Welded Duct Center.

[36] Shiba, Shoji, et al. *A New American TQM*, Cambridge, MA, Productivity Press, 1993.

7. Identify current methods of 'working around' the problem

The team should attempt to be as specific as possible when describing their current situation. As part of their process description, data on the current process should be collected for future analysis. This data will also serve as the 'before' information when evaluating the level of success achieved by the team.

Step 4. Identify the Preferred Target

At this step, the team steps away from the confines of the existing processes and develops a detailed picture of the preferred target state. The team should focus on creating new processes that are less complex than the existing processes. By working to simplify a process, it is possible to find an elegant solution to a problem that also contains an element of proactive improvement.

The key functions of this step are the following:

1. Perform benchmarking studies
2. Research relevant literature for best in class documentation
3. Describe the ideal process as it would exist in the future
4. Determine appropriate metrics and their desired levels based on customer requirements
5. Describe the future in terms of metrics, equipment, procedures, human resources, and culture
6. Identify elements that will prevent the process from returning to its previous state
7. Identify opportunities to simplify and streamline the process

The team must strike a balance between being constrained by their current mental models and describing an unrealistic process. This step benefits greatly from the cross-functional membership of the team. Since each team member has a different background and viewpoint, they can selectively combine these views to create a unique new process from the composite.

Step 5. Determine the Gaps Between Current and Preferred States

After the team has carefully analyzed their current situation and thoroughly described their desired future state, they need to compare these two different views. The goal of this step is to create a listing of the specific areas where the current methods fall short of their targets. This step is easier if the team has developed detailed descriptions and specific metrics of both the current and future states. An effort should be made to avoid any generic or ambiguous statements when describing these states and their resulting gaps.

The primary tasks of this step include the following:

1. Compare the current process data to customer requirements
2. Evaluate availability of data being used for decision making
3. Uncover known gaps in meeting customer requirements
4. Collect "language of report" information from process users[37]
5. Determine chronic process problem areas
6. Identify strategic issues that are related to the problem/opportunity

The team can perform pair-wise comparisons of equivalent metrics, methods, and strategies between the current and future states. These comparisons will allow the team to identify opportunities for improvement. The team should also plan to perform some prioritization of these opportunities. Affinity diagrams and K-J diagrams[38] are useful tools for this prioritization.

Step 6. Find the Causes of the Gaps

Now that the team has identified opportunities for improvements in the existing methods, the team must determine the causes of these gaps. The goal of this step is to identify all of the root causes of these gaps. Simply identifying relationships between various events will not provide the necessary insight required to permanently improve the process.

The critical tasks of this step are the following:

1. Collect quantitative data related to customer requirements
2. Perform root cause analysis (5 why's technique, cause and effect diagrams, etc.[39])

---

[37] Ibid.

[38] Ibid.

[39] Ibid.

3. Identify barriers and enablers that have led to the gaps
4. Identify strategic initiatives that prevent problem resolution
5. Evaluate role of management and existing incentive systems in supporting the gaps
6. Identify shortcomings in existing feedback methods
7. Document findings

An approach that has proven to be very useful for understanding complex processes and identifying causal relationships in a manufacturing system is 'System Dynamics'. There are several different software tools that can aid a team in effectively describing their manufacturing system and the relationships between components of the system. Two of the more popular system dynamics modeling programs are Vensim® and iThink®. This system dynamics model will also prove useful when the team is evaluating the effect that potential process changes will have on the system.

Step 7. Develop Plans to Eliminate Gaps

This step is essentially the 'Plan' part of the Plan-Do-Check-Act (PDCA) cycle. The results of this stage will depend heavily on the nature of the gaps and their causes, which were identified in the previous two steps. At this stage of the implementation effort it is critical to include the users of the existing process. Without their involvement it will be extremely difficult to get their buy-in of the implementation plan.

The planned changes in the existing process should be evaluated with consideration given to other changes taking place in the same area. The team needs to identify any interactions or potential conflicts with other process improvement activities. Developing implementation plans in isolation will typically lead to 'process silos' that create poorly integrated manufacturing systems.

The key activities of this step are the following:

1. Confirm 'desired' process performance levels based on customer requirements
2. Identify additional team members required to ensure process ownership and acceptance
3. Identify and address cultural barriers to process implementation
4. Determine training requirements for process owners
5. Create new incentive systems to encourage successful implementation

6. Determine supplier performance requirements and specifications to support new process
7. Uncover additional improvement needs and opportunities
8. Prioritize opportunities for improving the existing process
9. Establish improved feedback methods for future improvement activities
10. Integrate improved process with existing manufacturing system and initiatives

The resulting implementation plan should include the roles and responsibilities of those that are affected by the changes in the process. The team should also identify the necessary level of management support that is required for successful implementation. Other organizations that will be affected by these changes, such as union representatives, should be involved in these activities. This is also the appropriate time for the team to determine control mechanisms to ensure that the implementation is executed as planned.

Step 8. Implement the Plans

It is now time for the team to put their plans in place. This is the equivalent of the 'Do' step in the PDCA cycle. The initial implementation of the new process should be carried out on a limited basis until the process can be refined to 'iron out the kinks'. The preferred method for controlling the implementation is to select a subset of the overall manufacturing system that provides an effective representation of the overall system. This subset of the production system allows the implementation to be tested in a more controlled environment.

The primary functions of this step are the following:

1. Provide the necessary training and resources
2. Test improvement solutions on a small scale (pilot implementation)
3. Operate new process according to implementation plan
4. Utilize appropriate rewards and incentive system
5. Gather qualitative and quantitative data on key process measures
6. Solicit customer feedback during 'trial run'

When running the initial implementation pilot, the team should avoid interfering with the system. This allows the new process to run as it would in a wide scale implementation. Tampering with the process while it is operating will tend to create anomalies in the resulting data. The goal of this step is to truly test the new process in the same environment that it will be exposed to when implemented on a broad scale.

Step 9. Analyze the Results and Make Course Corrections

This step provides the team with an opportunity to reflect on their decisions and on their progress. These activities most closely align with the 'Check' and 'Act' steps in the PDCA cycle. The team is also given an opportunity to make any changes to the new process prior to wide scale implementation. If the team chose to model their manufacturing system, this step will allow them to verify the accuracy of their model. If the model is found to have flaws, the team should incorporate the necessary changes so that the model can be used for future evaluations.

The principal tasks in this step include the following:

1. Review quantitative data related to process performance
2. Determine if root cause of previous process problem has been reduced or eliminated
3. Verify that improvements in process performance have been sustained systematically, rather than ad hoc occurrences
4. Evaluate long term benefits of continued process operation
5. Compare process performance metrics with benchmark performance metrics
6. Evaluate training provided and incorporate improvements
7. Analyze documented procedures to identify opportunities for simplification
8. Document lessons learned from the team's experience to share with future teams

At the completion of this step the new process should be fully integrated with the remaining existing processes, and ready for full scale deployment. Any conflicts with the other elements of the manufacturing system need to be resolved prior to full implementation. When the new process is installed into the remainder of the manufacturing system, a staggered phase-in approach should be used. This will allow the team to identify and resolve any unforeseen difficulties prior to system wide implementation.

Step 10. Improve Continuously

The goal of this step is to migrate into the incremental process improvement phase using a Continuous Quality Improvement (CQI) approach. Once the above steps have been implemented and institutionalized, the team may need to continue meeting periodically to look for ways to improve upon their success. This approach is also consistent with the continuation of the PDCA cycle.

The primary tasks in this step include the following:

1. Refine process improvements as necessary
2. Implement the new process on broad scale (repeat steps 8 and 9 for all affected areas)
3. Develop improvement plans for metrics that have not see improvement
4. Communicate improved process flow and operating guidelines to process owners
5. Implement incentive systems to avoid regressing to previous process
6. Incorporate new process parameters into 'legacy control systems'
7. Incorporate new processes into standard operating procedures and daily activities
8. Gather and provide ongoing customer and supplier feedback
9. Provide feedback to management on implementation results and lessons learned
10. Disband process improvement team as appropriate
11. Hold and continually improve process performance gains (return to step 3)

Once the new process is in place, there will still be some additional effort required to support the process while it transforms from a 'new' process to an 'accepted' process. This transitory time is critical to the acceptance of the new process. There needs to be considerable attention paid to the cultural ramifications that the new process introduces. Incentive systems may need to be significantly modified to encourage the acceptance of the new process.

A.3 Critique of the Ten Step Method

This section describes some of the pros and cons of using the above described ten step implementation methodology. After using this approach to develop and implement a new process, I'm confident that most teams will find that the advantages of this methodology outweigh the drawbacks.

Advantages of the Model

A major benefit of using the ten step method is that the team is assured that no steps will be overlooked when working to implement a new process. This avoids the downfall that many teams suffer in their hurry to implement new processes. The most commonly skipped activities are in Step 3; documenting the current situation. Many teams fail to collect data on their current situation, which can later be used to determine if their new process is any better than the process that it replaced.

By providing a roadmap for a team to follow, they are given a 'yardstick' to track their progress toward reaching their destination: an improved process, successfully implemented. This gives the team instant feedback on how far they have come, and how far they still have to go before they can start seeing the results of their efforts. Hopefully, this feedback will help keep the team from getting too bogged down in any one step.

The ten step model is not overly constraining, which enables a team to have significant latitude in the tools that they use to achieve their goals. Although the examples provided list a handful of useful supplemental tools, these are by no means comprehensive. This process implementation methodology is simply a framework, the team should look for opportunities to use tools and methods that they are familiar with as they move through the ten steps of this methodology.

Drawbacks of the Model

Using this, or any other process implementation method, does not guarantee that the team will be successful. The final results of the team's efforts are still very much dependent on the quality of the data used and the abilities of the team members. If the team chooses to analyze poor data, even perfect analysis tools can not save them from bad data.

This approach for implementing processes is not a quick fix. Considerable time and effort is required to complete all ten steps of the above process. This rigorous approach to implementation may actually slow a team down that has all of the necessary information and has a clear idea of where they are heading. For example, the TPM implementation plan shown in Appendix B takes approximately 24 to 36 months to complete. And this is just steps eight through ten of the ten step process.

A.4 Summary

This ten step model is a compilation of several different product development concepts, proactive problem solving tools, and reactive problem solving tools. By combining the different tools and methods, the individual drawbacks of each tool are minimized. For example, many reactive problem solving tools do not address the activities required to carefully select the highest priority problem. Additionally, most product development tools fail to provide a feedback loop to make future course corrections. This model is also intended to capture the spirit of the 'Plan-Do-Check-Act' concept. The following chart shows the various quality improvement tools that are used throughout this methodology.

Step \ Tools	Brainstorming	Checksheet	Pareto Chart	Cause-and-Effect	Histogram	Scatter Diagram	Graphs and Charts	Flow Chart	Control Chart	Affinity Diagram	Tree Diagram	Matrix Diagram	Interrelationship	House of Quality	SPC/DOE
Step 1. Select Customer	●							●							
Step 2. Identify Problem	●	●	●		●		●	●	●	●			●	●	
Step 3. Current Situation		●	●		●	●	●	●	●	●			●	●	●
Step 4. Identify Target	●						●							●	
Step 5. Determine Performance Gaps							●			●				●	●
Step 6. Find Causes	●	●	●	●	●	●	●		●				●		●
Step 7 Develop Plans	●	●	●		●			●			●	●		●	
Step 8. Implement Plans	●						●								
Step 9. Analyze Results		●	●		●	●	●	●	●						●
Step 10. Improve Continuously	●						●		●						●

Figure 13: Quality Improvement Tools and the Ten Step Model

There are a couple of additional points that a team needs to keep in mind when working to implement or improve processes. It is extremely important that the development and implementation team have representatives from the organization that will eventually own the new process. Processes that are developed in a 'vacuum' and then handed-off to the using organization will rarely see the level of ownership and support that comes from being a part of the development and planning efforts.

Another important issue is the integration of any new process into the existing network of processes. If a new process is developed and implemented in isolation, it faces the possibility of becoming a 'process silo'. This problem is similar to the drawbacks that come with an organizational culture that is composed of 'functional silos'. These processes must be allowed to communicate and integrate just the same as the people within different functional disciplines must coordinate to optimize their collective efforts.

Appendix B: Total Productive Maintenance Detailed Description

This appendix provides additional information on the objectives, components, benefits, and activities of TPM that were briefly described in Chapter 3. This appendix also contains an examination of how TPM fits into the overall manufacturing system, and brief description of the activities required to implement TPM. This information is primarily based on the writings of Seiichi Nakajima, Terry Wireman, Charles Robinson, and Kunio Shirose. Additional information has been included from TPM training materials developed by Westcott Communications and BCAG. The intent is to synthesize these references, along with personal observations, to create a complete description of TPM and how it relates to the overall manufacturing system.

B.1 Objectives of TPM

The ideal goals of TPM are to achieve Zero Failures, Zero Defects, and Zero Accidents. Although these goals are extremely difficult to achieve, and in many cases may not be economically feasible due to the high cost of eliminating <u>all</u> failures, defects, and accidents; they provide a directional target that the organization can shoot for. To move an organization toward these goals, TPM provides the means to increase the amount of time that a piece of equipment is reliably available for production use. This requires significant effort to reduce the equipment degradation that may lead to equipment failures or production part variation. Additionally, TPM effects the equipment operator by providing an increased awareness, sense of ownership, and responsibility for the production equipment. The TPM approach to equipment management also includes a new set of metrics to measure the overall equipment effectiveness.

The implementation of TPM should not be seen as a short term fix to production problems. The full deployment of a TPM program "typically takes from three to five years".[40] Following the implementation of TPM through to fruition requires a focus on the costs of equipment over its entire life cycle. The elements of life cycle costs include acquisition costs, operating costs, maintenance costs, and conversion/decommission costs. Each of these costs can be further subdivided. For example, "the maintenance costs contain costs of repairs, maintenance labor costs, operator labor costs (during downtime), and equipment component parts costs".[41]

B.2 Eliminating Process Losses

To help focus improvement efforts, it us often helpful to categorize, or group the problems that the equipment is experiencing. Thinking in terms of production system 'losses' and grouping the problems based on the cause of these losses helps point out the common sources of equipment problems. However, to eliminate chronic problems that are reducing the equipment performance requires tracing the problems down to their root cause. The process losses described in this section are broken into groupings that will be used later, when discussing the calculation of overall equipment effectiveness.

Losses Due to Downtime

The production system losses that fall into this grouping are the result of the equipment being temporarily unavailable for production. These losses can be sub-divided into two categories: *Breakdowns* and *Setup and Adjustment*. Sporadic breakdowns, that are sudden or dramatic, are usually obvious and easy to correct. However, frequent or chronic minor breakdowns are often ignored or neglected after repeated unsuccessful attempts to cure them. To maximize equipment effectiveness, breakdowns must be reduced to the lowest possible frequency. This goal can be achieved by proactive replacement of worn parts during scheduled maintenance. It is almost always more cost-effective to replace a questionable part than to allow its failure to shut down equipment (remember: "a stitch in time saves nine").

---

[40] Nakajima, Seiichi, "Introduction to Total Productive Maintenance", Cambridge, MA, Productivity Press, 1984.

[41] Ibid.

Losses during setup and adjustment result from downtime, and producing defective products, when production of one item ends and the equipment is modified to meet the requirements of another item. Setup can be reduced considerably by making a clear distinction between internal setup times (operations that must be performed while the machine is down) and external setup times (operations that can be performed while the machine is still running) and by reducing internal setup time.

Losses Due to Poor Performance

This category focuses on equipment utilization that is lost as a result of the equipment being operated at less than maximum speed. The lost production capability falls into the sub-categories of: *Reduced Speed* and *Idling and Minor Stops*. If the maximum operating speed of a piece of equipment falls below the original design speed, a loss is incurred. This may occur due to excessive equipment wear, or due to lack of operator confidence in the manufacturing process. Well maintained equipment and a reliable manufacturing process will help minimize both of these problems.

Idling and minor stops refers to brief interruptions in processing. These stoppages generally stem from the need for some slight adjustment, such as tightening a bolt or holding fixture. Resolving a minor stop may require the correction of a small problem, such as equipment jams. The difference between these minor stops and equipment breakdown is typically a function of time and severity. Idling and minor stops can be rectified quickly, often without completely shutting the equipment down; breakdowns are associated with large or catastrophic failures.

Losses Due to Poor Quality

Just because the equipment is running, and running at full speed, does not guarantee that it is producing a satisfactory product. If the equipment output is not useable, the equipment may as well be shut off to conserve energy. The losses that come from producing poor quality products are separated into two classifications: *Process Defects* and *Startup Losses*. Defects in output are often generated by defects in the process related to equipment performance. The way to improve quality in these cases is to eliminate the root cause of the loss, by improving the equipment. These process defects include both chronic and sporadic production problems that result in parts that are not acceptable or must be reworked.

Startup losses are created by reduced product yield that occurs during the early stages of production; from machine startup to stabilization. The longer it takes for the equipment to achieve stabilization, the greater the amount of unusable output. Examples of this situation include producing unacceptable products, or having a reduced output, during the time required to reach operating temperature or speed. Reducing the time required for equipment parameters to reach their necessary state will minimize the amount of startup losses.

B.3 Major Components of TPM

Total Productive Maintenance involves improvements to production equipment, as well as making the practice of maintenance more efficient. This requires accurate planning and scheduling, access to reliable equipment information, and a good spare parts inventory system. It can also involve "designing or redesigning equipment to make maintenance easier and quicker to perform, or purchasing equipment that requires less maintenance".[42] TPM activities can effectively be collected in the following six separate components.

Education and Training

This element supports all the other TPM components by ensuring that employees have the necessary knowledge and skill to do a quality job while performing TPM related tasks. The affected employees include: management, maintenance personnel, operators and other stakeholders in the equipment operation. Education and training also provides a common vocabulary and an accurate understanding of the TPM goals for the manufacturing process.

Autonomous Maintenance

Autonomous maintenance requires the proactive involvement of equipment operators to eliminate accelerated equipment deterioration through: cleaning, monitoring, fastener tightening, data collection, and reporting equipment conditions and problems to the

---

[42] "Introduction to TPM Training", Westcott Communications, Inc.

maintenance staff. Further, the operators must work to develop a deeper understanding of their equipment which should improve their operating skills. Daily cleaning reduces wear on the machines and provides an opportunity to inspect for excessive wear and minor equipment malfunctions. The appropriate person can be notified, or corrective action taken, prior to excessive damage. Minor adjustments by operators, where appropriate, helps keep overhead costs low by avoiding a special trip to the machine by a maintenance mechanic. This immediate operator response assures adjustments are made before they can contribute to equipment breakdown or variations in production parts. Autonomous maintenance, practiced by an operator, or manufacturing work cell team member, will help to maintain high machine reliability, low operating costs, and high quality of production parts. Information collected by the equipment operators contributes to overall equipment effectiveness measures and to reliability and maintainability improvements for both new and existing machines.

Preventive Maintenance

Preventive maintenance is based on planned servicing of equipment and in-depth inspections to detect and correct conditions that might cause breakdowns, production stoppages, and premature wear. This function consists of periodic inspections, planned restoration of deterioration, and proactive replacement of suspect equipment components. While performing preventive maintenance, data is collected for equipment effectiveness measurements, reliability studies, maintainability metrics, and operating costs. Another target of this element is to reduce the time required for planned maintenance and eventually eliminate the requirement for unplanned repairs of equipment.

Planning and Scheduling

This element coordinates the production schedules, the preventive maintenance schedules and other activities requiring utilization of the equipment. Further, it assures that trained technicians with proper tools, equipment, parts, documents, and safe work instructions are coordinated with the equipment availability. Also included are dispatching activities to conduct planned maintenance or breakdown repairs in such a manner that maximizes overall equipment effectiveness and availability for production, while avoiding schedule disruptions.

Reliability Engineering and Predictive Maintenance

Predictive maintenance provides a process for improving equipment effectiveness by using a dedicated technical core group to identify and focus on chronic equipment problems. In addition, reliability engineering performs analysis for the root cause of problems and identifies actions and resources required to improve machine reliability and maintainability. This function is also responsible for developing predictive maintenance techniques such as vibration analysis, thermal analysis, and lubricant analysis. Further, it is responsible for development and feedback of reliability and maintainability data to equipment engineers and equipment suppliers.

Equipment Design and Start-up Management

This component of TPM is responsible for incorporating the knowledge gained from maintaining the existing equipment into new equipment designs. This information includes equipment performance, life cycle costs, reliability and maintainability targets, equipment testing plans, and operating documentation and training. This process requires joint planning and coordinating with other stakeholders involved in equipment start-up. The goal is to accomplish rapid and reliable ramp-up to designed production rate performance.

B.4 World Class Manufacturing and TPM

During the last decade, many manufacturing companies have made extensive use of benchmarking activities to determine 'best in class' performance for management practices. This section consolidates these manufacturing management practices into a small handful of high level principles. These principles of world class manufacturing are: Total Quality Management (TQM), Total Productive Maintenance (TPM), Just In Time Production (JIT), Total Employee Involvement (TEI), and Continuous Quality Improvement (CQI). These concepts form an umbrella which covers all of the components of an effective manufacturing management system. The following figure shows how these components can be represented, and that all components are equal and are moving in the direction of CQI.

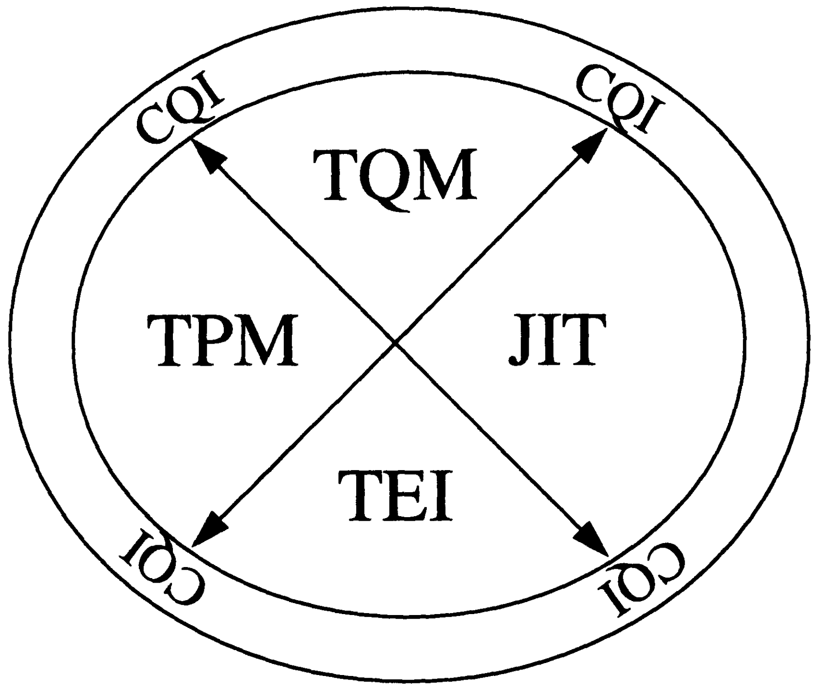

Figure 14: World Class Manufacturing Model

The following is a brief description of each of the world class manufacturing concepts.

- "Total Quality Management is an evolving system of practices, tools, and training methods for managing companies to provide customer satisfaction in a rapidly changing world. TQM improves the performance of companies in several areas: eliminating product defects, enhancing attractiveness of product design, speeding service delivery, and reducing cost, among others".[43]
- Total Productive Maintenance is a comprehensive, life cycle approach to equipment management that focuses on maximizing equipment effectiveness. TPM uses team based maintenance, preventive maintenance, and communication with suppliers to improve equipment performance and reduce manufacturing costs.
- Just In Time is an application of 'pull production' that focuses on reducing raw materials inventory, work in process inventory, and finished goods inventory. JIT often uses kanbans (visual cues to start production) for the shop floor scheduling system.

[43] Shiba, Shoji, et al. *A New American TQM*, Cambridge, MA, Productivity Press, 1993.

This approach allows the production system to quickly pass information up and down the value chain, and to avoid producing unnecessary or defective products.

- Total Employee Involvement is an approach that includes the employees in the decisions that affect the production system. This component of world class manufacturing builds on the belief that the best source of information on the production process is the employee that works within the process. The employees, with the proper training, tools, and guidance, are turned loose to improve the production system.
- Continuous Quality Improvement requires that all four of the above world class manufacturing concepts be continuously improved over their entire life cycle. The focus of CQI is long term, incremental improvements that provide evolutionary performance gains.

Total Quality Management and TPM

Total Quality Management (TQM) can be summarized as the "methods and tools necessary to achieve the following four levels of quality fitness".[44] A world class manufacturing company will typically mature from the level of "standards" to the level of "latent requirements" as they improve their quality management practices.

1. Fitness to Standard: Products are built per specification. Statistical Process Control (SPC) and other data collection techniques are used to assure the product is built as *intended by the designer*.
2. Fitness to Use: Products are built such that the product can be used as *intended by the customer*. Fitness to use also uses inspection methods to assure satisfaction of market needs.
3. Fitness of Cost: Products are built that are high quality, yet are produced at low cost. This requires that products not be reworked or rejected at the end of the manufacturing process. This is achieved via in-process inspection, feedback at each step, and implementing empowered work teams.

[44] Ibid.

4. Fitness to Latent Requirements: Products are built that meet the customer's needs before the customer is aware of the needs. This is achieved by spending time in the customer's environment to intimately learn their needs. The production system must be flexible, with minimal production lead time, to allow for moving quickly to satisfy the customer's before the competitions does.

Unfortunately, the TQM concepts are typically not described relative to the TPM concepts. However, I believe that the processes included in an effective TPM program will help to achieve all four of the above described fitness levels. For example, the improved repeatability and reliability of the production equipment lowers the manufacturing costs associated with defective parts, production delays, and slow production ramp-up. Also, reducing set-up times, as part of a TPM program, allows manufacturing to react more quickly to changes in customer demands.

The tools of TQM, such as Quality Improvement Tools (cause & effect, pareto diagram, etc.), Management and Planning Tools (KJ method, arrow diagram, etc.), and Statistical Process Control (SPC) can effectively be used within TPM to develop, implement, and enhance the TPM program.

Just In Time and TPM

The implementation of Just In Time (JIT) is the component of world class manufacturing that is the most closely linked to a successful TPM program. Attempting to implement JIT with production equipment that excessively and unexpectedly breaks down, and produces defects, may be a costly endeavor. A companies failed attempts to implement JIT may be traced back to the fact that their excess inventory was hiding the problems inherent in their manufacturing processes. The work in process inventory can cover the problems of unreliable equipment, poor quality assurance processes, and erratic production schedules. Trying to eliminate this cushion of inventory, without first resolving the underlying problems, is a recipe for disaster. The manufacturing organization must balance the costs of carrying their excess inventory against the costs of improving their equipment performance. In some cases, it may make economic sense to carry a little extra inventory to hedge against the risk of stopping the entire production line due to one equipment failure.

The utilization of kanbans to signal production requirements can be successfully combined with a TPM program. Once a preventive maintenance schedule is determined, a special 'maintenance kanban' can be created. This special kanban is then inserted into the kanban system so that the signal for maintenance appears at a predetermined frequency, based on equipment usage. When a production worker receives this maintenance kanban, the required maintenance activities are performed at that time. Of course this extra kanban must be accounted for in the overall production schedule; otherwise a gap in the product flow will be created that must pass through the entire production system.

Total Employee Involvement and TPM

Total Employee Involvement (TEI) is about empowering the workers to take control of, and responsibility for, their role in the manufacturing system. TEI strives to harness and focus the collective energy of all the employees; truly making them the companies most valuable and treasured asset. However, just *saying* the employees are empowered does not make it so. They must be given the necessary training, tools, and data to effectively take ownership of their assignment. If the employees are given decision making authority, they must be given clear direction on the organization's priorities. This requires a cohesive set of manufacturing strategies. As part of world class manufacturing, I believe that TEI is one of the more powerful concepts.

One of the major components of TPM, Autonomous Maintenance, gives equipment operators much more responsibility for the daily operation of their equipment. Through Autonomous Maintenance, the operators take over most of the less technical maintenance tasks for their production equipment and collect data on equipment performance. In doing so, they learn what helps and what hinders equipment performance. This deeper understanding of their equipment enables them to identify many improvement opportunities. Further, the metrics associated with TPM must focus attention on the process, not the people. This helps eliminate an environment of finger pointing, and to develop a more trusting and cooperative relationship between manufacturing workers, maintenance, and management.

Much of the required training for TPM includes material on teamwork, Continuous Quality Improvement, and problem solving tools which help the employees perform more effectively in a team based environment. By allowing the TPM plans to be developed and implemented by the employees, management is sending a strong message that they trust the team's abilities. This support is a must for encouraging Total Employee Involvement.

Continuous Quality Improvement and TPM

Implementing a TPM program provides the manufacturing system with a step-function improvement in performance. Unfortunately, these types of jumps in performance are few and far between. This necessitates an approach for making gradual process improvements between these occasional step-function improvements. Adopting a Continuous Quality Improvement (CQI) attitude addresses the incremental improvements that can be realized on an on-going basis. CQI requires everyone involved in the production system to constantly look for improvement opportunities. CQI must be well integrated with the remainder of the manufacturing processes to ensure that all of the processes are improving in concert; CQI provides the glue that holds the other four components together.

The first priority in a good CQI program is to simply avoid slipping backward. Many major improvement programs fail to 'hold their gains', and immediately begin regressing toward their previous state. Total Quality Management (TQM), previously described in this appendix, provides an excellent tool kit for both *reactive* and *proactive* problem solving. These tools need to be employed to continuously improve the performance of the manufacturing system. Many of the activities described in TQM are done in the spirit of continuous improvement.

The TPM approach to equipment management provides the means to get the run-down production equipment back into shape, as well as assures that new equipment is not allowed to degrade. The existing equipment must continuously be evaluated for opportunities to reduce set-up times, improve reliability, and reduce defects and delays. Additionally, the knowledge gained from the existing equipment must be shared with the equipment suppliers to improve future equipment designs.

JIT production is not something that can be implemented with the flick of a switch. JIT requires progressively reducing the production system's inventory, while simultaneously improving the overall scheduling system. Successful implementation comes from an iterative approach where production processes are improved, inventory is reduced, then the process is further improved and the inventory is additionally reduced. This is continued until either the inventory is eliminated, or the existing process can not yield additional improvements.

Finally, CQI can not be achieved without the full support of the employees. The improvement ideas, the plans for implementation, and the deployment of improved processes all require Total Employee Involvement. Whether it is through a formal suggestion system, accelerated improvement workshops, or informal work teams, the implementation of CQI rests in the hands of the people working on, and in, the manufacturing system.

Lean Manufacturing and TPM

Lean manufacturing techniques are typically considered to be synonymous with the Toyota Production System (TPS). Lean manufacturing is a collection of concepts and activities that strive to eliminate all waste in the production system. Simply put, lean manufacturing gets "the right parts to the right place at the right time, with zero waste". The two most common forms of waste that are addressed by lean manufacturing are defects and excessive inventory. Lean manufacturing improves the effectiveness and efficiency of the manufacturing system by increasing the system's flexibility to accommodate variety in product mix and variation in throughput, while focusing on optimizing the overall system.

The components of the Toyota Production System (TPS), as created by Taiichi Ohno, can be aligned with the primary goals of TPM. The following figure shows the basic features of the TPS and their relationship to the six process losses of TPM.[45] This chart has

[45] Nakajima, Seiichi, "Introduction to Total Productive Maintenance", Cambridge, MA, Productivity Press, 1984.

been modified slightly from the original to incorporate a common naming convention for the six process losses.

TPS \ TPM	Breakdowns	Setup and Adjustment	Idling and Minor Stops	Reduced Speed	Process Defects	Startup Losses
Implementing Flow Processes	●					
Eliminating Defects					●	●
Stockless Production	●	●				
Reduced Lot Size		●				
Quick Setup		●				
Standard Cycle Times	●	●	●	●	●	
Standard Sequence	●	●	●	●	●	
Standard Idle Time	●	●	●	●	●	
Visual Control	●	●	●			
Improved Operability	●	●				
Improved Maintainability	●					

Figure 15: Toyota Production System and TPM

B.5 Benefits of TPM

When facing the decision of whether or not to implement a TPM program, a good question to ask is: *What's in it for me?* (what are the benefits?). The bottom-line answer to this question is: *TPM helps you reduce your manufacturing costs!* This answer is particularly true for organizations that make extensive use of automation and sophisticated production equipment. Of course, the actual amount of cost savings will depend heavily on the current status of the manufacturing system and the type of production process. If the equipment is already performing well, the organization may be better off focusing on other opportunities to improve the production system (e.g. inventory reduction, employee skill training, cycle time reduction, etc.). Also, if the plant currently has excess capacity, looking for new customers for your products may provide better returns than improving the equipment reliability. Even though TPM has been proven to yield extraordinary benefits for many companies; each facility must carefully evaluate their current situation to determine if their manufacturing system can gain any advantage from these benefits.

Although TPM implementation is not free; it requires training, new data collection procedures, and changing roles and responsibilities; the benefits and paybacks have been documented in many industries. These benefits are achieved through improved equipment reliability and utilization, reduced equipment variation due to wear and tear, and less maintenance 'fire fighting'. Further, the increased availability of the equipment also allows the organization to defer the purchase of additional equipment to satisfy increases in production demand.

Many companies have demonstrated that increasing scheduled maintenance activities (preventive maintenance) will drastically reduce unscheduled maintenance (breakdown repairs), and that the total maintenance costs decrease as planned maintenance replaces unplanned breakdowns. The incentive to reduce these maintenance costs is motivated by the observation that "maintenance costs are typically 15%-40% of the cost of goods sold for a manufacturing firm".[46] These costs can increase drastically when excessive breakdowns occur. However, there is a trade off that must be made between the costs of performing excessive amounts of preventive maintenance and allowing rare breakdowns. The organization must determine their costs incurred from breakdowns and balance this against the cost of avoiding these breakdowns to identify the optimal amount of preventive maintenance. In an effort to identify the proper maintenance mix, some companies have estimated that "the average cost of equipment failure is four times more than the cost of the repair".[47] In this case, it would be cheaper to allow the equipment to fail once than to perform preventive maintenance four times.

---

[46] Wireman, Terry, "Total Productive Maintenance, An American Approach", Industrial Press Inc., 1991.

[47] "Introduction to TPM Training", Westcott Communications, Inc.

Implementing TPM has the additional benefit of improving product quality, which reduces rework costs and increases customer satisfaction (due to consistently superior quality). The following sections provide many examples of the benefits that may be reaped as companies successfully implement TPM programs.

Reduced Variation

Variation in a manufacturing system comes in many forms: hardware variability, throughput variation, inventory variation, etc. In many cases TPM can effectively decrease the sources of these variations, the frequency of their occurrence, and improve the robustness of the production system.

In the case of hardware variability, TPM can eliminate sources of variation by improving the repeatability of the production equipment. This reduction is achieved by systematically tracing the sources of variation from the critical product features (key characteristics) down to the equipment and process parameters. Tracing the relationships between product features and process parameters is not a simple task. The first step in this activity is to determine which product features are most critical to satisfying customer requirements (see Chapter 2 for a description of key characteristics). From this point, Design Of Experiments (DOE) techniques can be employed to identify the process parameters that have the greatest impact on these key characteristics. Additionally, DOE techniques will help identify the parameter values that produce the best products.

Once these parameter settings have been determined, they can be monitored by the operator using SPC control charts to provide in-process data. If an anomaly is observed in the SPC data, the equipment operator is alerted that the resulting production part may not be acceptable and requires additional investigation. Further, these process parameters should be aligned with the maintenance task that has a direct impact on their stability. For example, if a machine cutting tool can not achieve the preferred operating speed, it may be due to excessive bearing wear due to poor lubrication. Chapter 2 provides a further discussion of the relationship between TPM and hardware variability of an assembly.

Improving the reliability of the equipment, by implementing TPM, will also reduce variability in the manufacturing system throughput. Sporadic equipment breakdowns and unscheduled repairs are major causes of fluctuations in throughput. Implementing TPM will minimize these equipment reliability problems. An effective TPM program permits the equipment to run at full speed when necessary, with the only downtime being for planned maintenance. Also, the planned maintenance can be scheduled with the production scheduling system so that there is no disruption to the forecasted throughput.

Inventory fluctuations can also be attributed to equipment reliability and the resulting throughput fluctuations. Additionally, reliable equipment with high possible utilization rates allows the manufacturing system to react more effectively to changes in customer demand. However, it is important to remember, just because the equipment can run at full speed 24 hours per day, does not mean that it should be run this hard. The higher possible utilization rates means that the organization no longer needs to store excess inventory, or work excessive overtime, to cover customer demand fluctuations. The production equipment can simply ramp-up to a higher throughput when necessary. This extra production capacity comes from having less breakdowns and unscheduled maintenance, and from making the equipment capable of running at its maximum designed speed.

Companies that have successfully implemented TPM have seen "reductions in breakdowns of up to 80%-90%, cost of defects drop by 55%",[48] "product lead times cut by 50%-75%, and on-time deliveries increase 50%-95%".[49] These levels of improvement can not be expected by every facility implementing TPM. However, they document the large potential gains that some companies may achieve.

Increased Productivity

Eliminating unscheduled downtime and excessive rework allows the organization to spend more of their time on the value-added tasks, such as producing good parts. Implementing TPM establishes processes and metrics that focus attention on minimizing the non-value-added tasks. The resulting increase in productivity applies not only to the

---

[48] Imai, Masaaki, "Kaizen, The Key to Japan's Competitive Success", New York, NY, McGraw Hill, 1986.

[49] Robinson, Charles J., and Andrew P. Ginder, "Implementing TPM, The North American Experience", Portland, OR, Productivity Press, 1995.

equipment, but to the people working in the manufacturing system as well. Production workers are no longer forced to wait around while their equipment is repaired, and the maintenance staff is no longer required to put off planned maintenance and equipment analysis work while they scramble to fix the broken equipment.

An effective TPM program also establishes metrics that focus on reducing equipment set-up and change over times. TPM encourages changing equipment set-up processes to allow the next product's configuration to be set-up while the equipment is still running on the existing products. Set-up reduction is one of the major components of implementing a pull production system, such as Just In Time.

The documented gains from TPM implementation include "equipment productivity increases from 50%-80%"[50], "value-added time per person increasing by 100%-150%, labor productivity increases of up to 150%"[51], and "set-up times dropping by 50%-70%".[52]

Reduced Maintenance Costs

The changing role of maintenance from breakdown repair to proactive improvement enables the organization to reduce its overall maintenance costs. The traditional fire fighting approach to equipment maintenance forces the maintenance organization to carry extra staff members to handle the wildly fluctuating and unpredictable workload. By using scheduled maintenance events, the organization can level-load their work across all staff members. Further, the implementation of TPM's autonomous maintenance removes many of the less technically challenging tasks from the maintenance staff's workload. This frees up the maintenance staff to focus on proactive equipment improvements, equipment performance analysis, and simplification of existing maintenance practices. This transition of responsibility requires an enlightened management team that focuses on the potential gains from improved maintenance, rather than focusing on the cost savings from simply reducing the maintenance staff headcount. There is an additional benefit from running the

---

[50] Ibid.

[51] Nakajima, Seiichi, "TPM Development Program", Cambridge, MA, Productivity Press, 1989.

[52] Imai, Masaaki, "Kaizen, The Key to Japan's Competitive Success", New York, NY, McGraw Hill, 1986.

equipment more efficiently: reduced energy costs. The equipment spends less time idling and operates more effortlessly due to TPM. Although the gains from reduced energy consumption may not be staggering, they are still reductions in the overall manufacturing costs.

The following data provide examples of the benefits that very successful companies have received from their TPM program: "maintenance spending reduced by 40%, energy conserved by 30%, and reduced maintenance labor by 60%".[53]

Reduced Inventory

Any manufacturing organization that uses unreliable equipment must maintain an unnecessarily large stock of finished goods to fulfill the customer demand while the equipment is non-operational. The more unreliable the equipment, the larger the necessary stock of finished goods. If a given production line is composed of unreliable equipment, the work-in-process inventory must be kept higher than desirable to accommodate equipment performance uncertainty. All of this extra inventory can create many problems: changes in customer requirements take too long to incorporate; the new product lead time must allow for using up the finished goods and in-process inventory. Further, any defective parts that are produced can sit in the in-process inventory waiting to be discovered at the next step in the production process. The inventory is effectively hiding these production problems. Implementing a TPM program removes much of the uncertainty in the throughput and cycle time of the production system.

The spare parts for the production equipment are another source of unnecessary inventory holding costs. The spare parts are used to make repairs to the equipment, which could occur at any time on unreliable equipment. Once again, the uncertainty in the equipment performance requires extra inventory. Through reliability engineering, data collection and analysis, the maintenance staff can develop an accurate estimate of the necessary spare parts and the frequency of their usage. Implementing TPM will allow the

---

[53] Nakajima, Seiichi, "TPM Development Program", Cambridge, MA, Productivity Press, 1989.

maintenance technicians to perform the necessary analysis to optimize their spare parts inventory policy.

Companies that have implemented TPM have been able to "increase inventory turn rates by as much as 200%"[54], "slash inventory levels by 35%, and reduce spare parts costs by 20%-30%".[55] However, these gains are not likely to be achieved by simply implementing TPM in isolation. Additional effort should be applied to reducing inventory via improved scheduling systems and synchronized production processes.

Improved Safety

The initial steps in implementing the autonomous maintenance activities of TPM create an environment that could easily reduce safety and increase accidents. This is the result of equipment operators taking on additional and unfamiliar maintenance tasks, for which they may not have been effectively trained. Since these tasks are new to the operators and they often involve potentially hazardous activities (removing debris from equipment, inspecting chains and gears, etc.), they pose a new threat to the safety of the operator. Therefore, ensuring the safety of the operators must be a primary function of the TPM implementation plan. This requires extensive training, developing 'fool-proof' maintenance tasks, and implementing improved procedures. Also, by performing the routine maintenance tasks on a frequent basis, the operators develop a better understanding of their equipment. This new knowledge helps the operator make more intelligent decisions to reduce the potential hazards that the equipment presents. The safety of all individuals involved with the equipment must be a top priority of any good TPM program.

The benefits of the improved safety within TPM have allowed some companies to "reduce their accidents essentially to zero".[56] Another side benefit of the TPM program is that pollution is often reduced due to more efficient equipment, which extends the safety improvements to include the surrounding community.

---

[54] Ibid.

[55] Robinson, Charles J., and Andrew P. Ginder, "Implementing TPM, The North American Experience", Portland, OR, Productivity Press, 1995.

[56] Nakajima, Seiichi, "TPM Development Program", Cambridge, MA, Productivity Press, 1989.

Improved Morale

The final benefit discussed here (although additional benefits certainly exist) is employee morale. As with any change in the workplace, their is bound to be some disruption from implementing TPM. However, this does not necessarily have to be all negative. Since TPM uses employee teams to develop the implementation plans and to deploy these plans, the operators are 'in the drivers seat', and can now be empowered by management and given increased levels of control and ownership over the equipment. This ownership allows the operator to take more pride in their equipment and to make informed decisions on how best to run the equipment. Obviously, this requires management support, since the operators are now assuming decision making authority. If the managers are unwilling to relinquish control of these decisions, morale may end up suffering, rather than improving.

The maintenance technicians now have the time to perform equipment analysis, work with equipment designers, and work on other technically challenging tasks. The maintenance staff will not necessarily see a drop in their workload due to handing routine maintenance tasks to the operators. They may simply see a shift to more proactive maintenance activities such as working to develop preventive maintenance requirements for the equipment. This change also requires management support to allow the maintenance staff to develop their skills in these areas.

Improved employee moral is typically difficult to measure (how do you measure happiness?); however, some companies have observed "better results in employee surveys, additional improvement ideas submitted (200% increase), and more small team activities (up by 200%)".[57]

B.6 Overall Equipment Effectiveness

One of the criticisms of implementing new manufacturing processes is that it is often difficult to quantify the benefits. This can also be the case with implementing a TPM program if this concern is not addressed in the initial planning. Organizations all too often fail to collect useful 'before' data that can later be compared to 'after' data. An additional,

---

[57] Ibid.

complicating factor is the difficulty in assigning the observed benefits to the responsible improvement activity. An excellent method, described in much of the TPM literature, for tracking the progress of a TPM program is known as Overall Equipment Effectiveness (OEE).

OEE provides the means to evaluate the production process by measuring the effective utilization of the capital assets. The goal of OEE measurements is to establish a focus on eliminating the six process losses previously described in this appendix. The relationship between the six process losses and OEE is shown in the following figure.

6 Process Losses	Type of Loss	OEE Calculation
Breakdowns	Equipment Availability	Availability
Setup and Adjustment		X
Idling and Minor Stops	Performance Efficiency	Efficiency
Reduced Speed		X
Process Defects	Quality Rate	Quality
Startup Losses		**= OEE**

Figure 16: Six Process Losses and Overall Equipment Effectiveness

Calculating Overall Equipment Effectiveness

Each of the components of the OEE calculation (availability, efficiency, and quality) have sub-component data that must be collected by equipment operators in order to calculate the OEE value. One of the benefits of OEE is that the data collection itself also provides an opportunity for equipment operators to learn more about their equipment. The final OEE value serves primarily as a basis of comparison to monitor the process improvements resulting from TPM. An additional benefit of measuring OEE is that each manufacturing cell within a plant can work to maximize their OEE without creating conflicts that sub-optimize the overall production system. This alignment of targets occurs because high OEE values can be achieved without producing unnecessary inventory, or running equipment just to achieve high utilization rates.

Calculating Availability

Availability is essentially a measure of the equipment's actual up-time, relative to the planned up-time.

$$\text{Availability} = \frac{\text{Operating Time}}{\text{Loading Time}} = \frac{\text{Loading Time - Unscheduled Downtime - Setup Time}}{\text{Loading Time}}$$

- Loading Time = Time Available - Planned Downtime (e.g. breaks & prev. maint.).
- Operating Time = Time that the equipment is actually operated.

Example: 1440 minutes in a 24 hour day
- 100 minutes scheduled for lunches and breaks
- 50 minutes for planned meetings and team activities
- 420 minutes for not using a third shift
= 870 minutes total Loading Time for this particular day

If setup times required 150 minutes this day
If unscheduled downtime used 50 minutes this day

$$\textbf{Availability} = \frac{(870 - 150 - 50)}{870} = .77 = \textbf{77\%}$$

Calculating Efficiency

Efficiency reflects whether the equipment is running at its *designed* full capacity.

$$\text{Efficiency} = \frac{\text{Ideal Cycle Time X Total Throughput}}{\text{Operating Time}}$$

Example: If ideal cycle time = 4.0 minutes
If total throughput = 135 parts this day
If operating time = 670 minutes (from Availability calculation)

$$\textbf{Efficiency} = \frac{(4.0 \text{ X } 135)}{670} = .80 = \textbf{80\%}$$

Calculating Quality

The quality rate is a measure of the processes ability to produce products without producing defective parts.

$$\text{Quality} = \frac{\text{Total Throughput - Total Defects}}{\text{Total Throughput}}$$

- Total Throughput = Good parts + Rejected parts + Reworked parts + Returned parts.
- Total Defects = Rejected parts + Reworked parts + Scrap + Returns.

Example: If total throughput = 135 parts
If total rejects = 1 part

$$\textbf{Quality} = \frac{135 - 1}{135} = .99 = \textbf{99\%}$$

Calculating OEE

OEE is the combination of these three metrics to determine the *Overall Equipment Effectiveness*.

OEE = Availability X Efficiency X Quality

Example: If Availability = .77 (from previous examples)
If Efficiency = .80 (from previous examples)
If Quality = .99 (from previous examples)

OEE = (.77) X (.80) X (.99) = .61 = **61%**

Relationship of OEE to Manufacturing Costs

The simplest method to communicate the relationship between OEE and manufacturing costs is through the use of a hypothetical example. Since virtually every production process will have different trade-offs for the cost of defects vs. the cost of set-up times, there is no accurate means to generalize the value of improving OEE by one percent. The following example was developed by Steve McConnell, of Boeing's Wichita Division, to teach the benefits of using OEE as a measure of manufacturing performance.[58]

Given Data:

- The manufacturing cell produces a variety of small aluminum parts using an extrusion mill, which makes finished parts from raw material in the same machine.
- The manufacturing cell is set up to run two shifts. The cost of the operator includes wages and benefits; the cost of the equipment includes utilities and depreciation. The current rate used to cover these costs is $25.00/hour (remember, this is hypothetical).

---

[58] McConnell, Steve, et al. *Overall Equipment Effectiveness Training*, Boeing Documentation, 1995.

- The manufacturing cell requires raw material to form into finished goods. The cost of the raw material is $100/stick (the material is delivered in the shape of a long rod).
- The manufacturing cell has transportation costs for bringing in raw materials and delivering finished goods.
- The manufacturing cell has a handful of support personnel for finance, planning, scheduling, NC programming, and clerical support. These people providing miscellaneous support are considered an overhead expense which costs $400/day.
- The maintenance for the cell includes all necessary parts and labor. The cost of maintenance is based directly on the amount of production hours. The current rate is $10/production hour.

Scenario 1 (Baseline situation):

Based on historical data that the manufacturing cell has collected, they find that their current OEE is 62.5%. Using their historical data, they estimate the following costs for a proposed bid on an order for 100 parts.

Raw Material =	$1,000	(10 sticks @ $100/stick)
Operator & Equipment =	$400	(16 hours @ $25.00/hour)
Miscellaneous Support =	$400	(required to support 2 shifts)
Transportation =	$150	(estimate for 100 part order)
Maintenance =	$160	($10/production hour @ 16 hours)
Total Costs =	**$2,110**	**($21.10/part)**

Scenario 2 (Impact of low quality rate):

Due to a problem with the equipment (wrong NC program was run), the cell is forced to scrap 20 parts. This drops the quality rate to down to 80% (since you have to make 120 parts to get 100 good ones). This drives the OEE down to 52.6%. The costs for this 100 part order are affected as follows.

Raw Material =	$1,200	(you now need 12 sticks)
Operator & Equipment =	$504	(extra time required due to scrapping parts)
Miscellaneous Support =	$415	(extra time required to fix NC program)

Transportation = $175 (increase due to moving extra parts, and scrap)

Maintenance = $192 (increased since the production hours increased)

Total Costs = $2,486 ($24.86/part)

Scenario 3 (Impact of low performance efficiency):

Due to a problem with the equipment, and having a relatively inexperienced operator, the equipment was only operated at 50% of its maximum rate. Fortunately, the quality rate was back up to its baseline level. This drops the OEE down to 32.3%. Once again, the costs are adjusted to accommodate the poor efficiency.

Raw Material = $1,000 (you only need 10 sticks)

Operator & Equipment = $800 (since it now takes twice as long)

Miscellaneous Support = $800 (since they are supporting 4 shifts of work)

Transportation = $150 (this returns to the baseline level)

Maintenance = $320 (since the process was run for twice as long)

Total Costs = $3,070 ($30.70/part)

Scenario 4 (Impact of low equipment availability):

Due to a four hour breakdown, the equipment was unavailable for production for half of one shift. Fortunately, no parts were scrapped in the breakdown and the following ramp-up was virtually instantaneous. The result of the breakdown was an OEE of 50%. As expected, the production costs are affected by the breakdown.

Raw Material = $1,000 (you only need 10 sticks)

Operator & Equipment = $530 (since the process had to wait to fix the breakdown)

Miscellaneous Support = $400 (this group had no problems to fix)

Transportation = $150 (this returns to the baseline level)

Maintenance = $450 (since they had to work extra to fix the breakdown)

Total Costs = $2,530 ($25.30/part)

This scenario evaluation process can be continued until a trade-off curve is generated that reflects the OEE value vs. manufacturing costs. The following figure shows the trade-off curve for the hypothetical manufacturing cell described above.

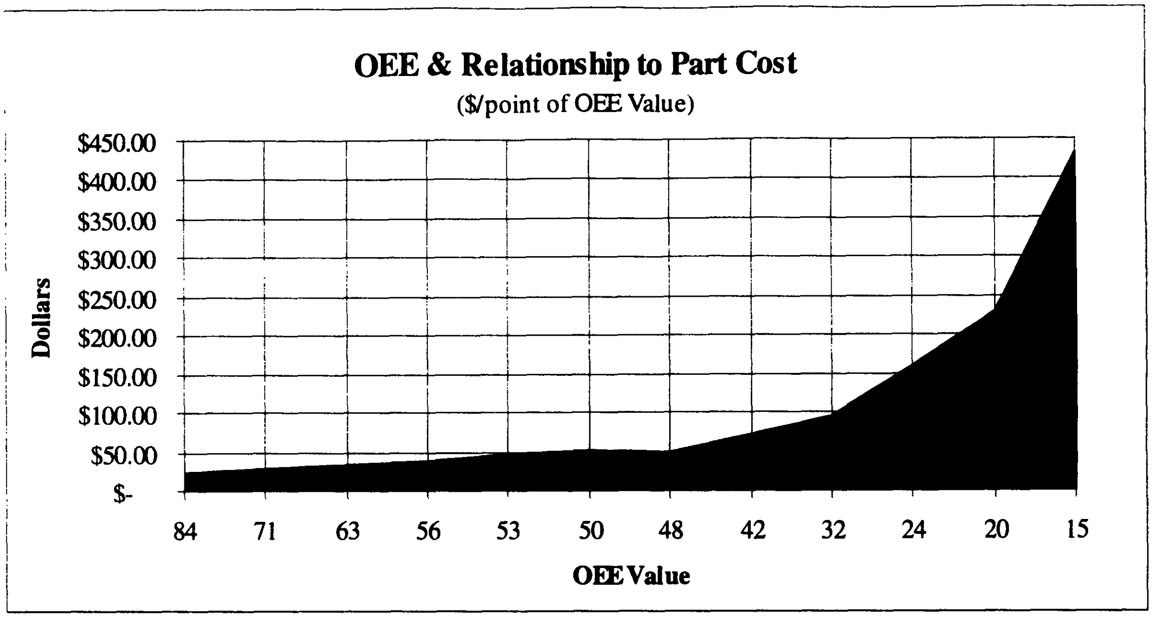

Figure 17: Relationship of OEE to Manufacturing Costs

This curve shows that improving OEE has a diminishing return for reducing the manufacturing costs. Although this particular curve is only truly accurate for this hypothetical factory, the overall shape of the curve is generally applicable. Essentially, when OEE is very low, tremendous savings are possible with small improvements in OEE. According to most literature, the target OEE for a world class manufacturing company is given as 85%. However, as previously mentioned, I believe that different manufacturing processes will have different trade-offs which justify different OEE targets.

Collecting Data for Overall Equipment Effectiveness

The act of collecting the necessary data to calculate OEE is best accomplished by creating easy to use daily data collection sheets for the equipment operators. These sheets should provide spaces for entering: total time the equipment was available, planned downtime, and unplanned downtime due to breakdowns, setups, adjustments, and minor stops. This information is used to determine equipment availability. Further, the total daily throughput (both good and bad parts) and ideal cycle time must be recorded for calculating performance efficiency. Finally the daily total of defects (rejected, scrapped, or reworked) needs to be documented in order to calculate the quality rate. Collecting the raw data in a structured format also simplifies the subsequent OEE calculation steps.

Once the raw data has been collected by the operators, the values for availability, efficiency, quality, and OEE can be calculated and then monitored using SPC control charts. Using control charts facilitates identifying long term trends, as well as sporadic events. As with any other control charting process, any out of control events should be evaluated to identify and eliminate the root cause of any undesirable event. If the control chart shows a downward trend in OEE, the availability, efficiency, and quality measures can then be examined from historical data to identify which of these three are contributing to the decline in OEE. From here, the historical raw data can be evaluated to identify where the problem lies. This basic method of data collection, and simple OEE calculation allows the operators to easily keep an eye on their equipment's performance.

However, if the OEE data is collected by the operators, but not used for decision making, the data collection activities will quickly drop to a low priority. It has been my observation that the operators are usually quick to see that their data collection efforts are simply creating data for the sake of data. Therefore OEE data should be used to prioritize the TPM implementation efforts, focus process improvement projects, and determine equipment replacement requirements. Also, having the operators collect this data gives them information to make decisions on how to best run their equipment. For example, they can determine if it is better to run the equipment at half speed and limp it to the end of the shift, or if the equipment should be shut down for four hours to perform repairs mid-shift. This type of decision making enables the workers to take more responsibility for the production system, and leads to an empowered workforce.

B.7 TPM Implementation Plan

As previously mentioned, TPM implementation requires a long term commitment to achieve the benefits of improved equipment effectiveness. Successful implementation also requires a significant amount of training, management support, and teamwork. This section provides summary information on a unique implementation plan that I believe will help an organization reach full TPM deployment in approximately 36 months. However, the amount of effort required for each of these tasks will vary depending on the sophistication of the equipment and its current condition. A more detailed example of this TPM implementation plan, including data collection, team membership, and training requirements can be found in Appendix C.

Task 1: Form TPM Management Support Team

The function of the Management Support Team is to develop the initial scope of the TPM program and provide the necessary support. Also, this team should maintain involvement in the TPM implementation to maintain some ownership of the detailed implementation plans that will be developed by their staff.

Task 2: Form TPM Planning Team

The TPM Planning Team will create the prioritized sequence of implementation for the TPM program. The information gathered during this step (such as OEE measurements) will reflect the state of the equipment 'before' the implementation of TPM.

Task 3: Form TPM Implementation Team

This team will develop and implement the detailed activities of the TPM program. The team should be composed of the individuals that will implement these detailed plans to help give them ownership of the resulting plans.

Task 4: Introduction to TPM Training for Implementation Team

This step will provide introductory training and provide the motivation to the implementation team to improve their equipment. This will be accomplished by communicating the goals and metrics of the Management Support Team & Planning Team. The team will also receive an overview of the components and activities of a TPM program.

Task 5: Implement 'Lockout/Tag/Tryout' Safety Procedures

This step will establish processes and supporting procedures that reduce the possibility of accidents for everyone involved in the maintenance of the equipment. The training provided in this step is typically required by safety regulatory agencies for individuals involved in equipment maintenance activities.

Task 6: Establish 'Cleaning is Inspection' Techniques

This step is intended to make the operators more familiar with their equipment through regular cleaning, inspecting, and data collection. It is the beginning of the transfer of knowledge from maintenance technicians to equipment operators. The equipment will receive extensive initial cleaning, and situations that make daily maintenance difficult will be identified during this step. This step also incorporates the requirements found in most housekeeping improvement programs.

Task 7: Implement Visual Controls

The goal of this step is to develop a system of color coding, labeling, mapping, and standardizing that creates a common understanding of the workplace. These visual controls should easily distinguish between what is normal and what is not, and make abnormalities and waste obvious to the casual observer. This technique provides visual cues to help uncover needs for improvement, and to simplify the inspection and data collection activities.

Task 8: Standardize Lubrication Processes

This activity is intended to educate the team on the requirements for proper lubrication, and to develop standard methods for ensuring proper lubrication. The team will also look for opportunities to reduce the variety of lubricants required for the equipment. The amount of effort for this step will vary depending on the particular equipment.

Task 9: Perform Process Improvement Exercise

This exercise provides an opportunity to stop and reflect on the progress made thus far and make necessary course corrections. This is the 'Check-Act' portion of the P-D-C-A cycle. The team will also quantify the benefits of their TPM implementation efforts by comparing current data to the original data collected for the prioritization planning team.

Task 10: Finalize & Standardize Autonomous Maintenance

This is the final step in the Autonomous Maintenance (AM) phase of TPM implementation. The team will stabilize and document the AM activities, provide the remaining training required for team based AM, and integrate these activities with the existing manufacturing activities. For example, the daily inspection checklists are included in the production plans and schedules.

Task 11: Develop Preventive Maintenance Plans

The goal of this step is to develop a component level equipment maintenance schedule for planned maintenance activities. A method for managing the equipment spare parts inventory will also be developed. This requires understanding the equipment at the component level, as well as knowing the effects of equipment failure. Data collection and analysis plans are developed that allow the maintenance staff to identify chronic equipment component problems.

Task 12: Integrate Production and Maintenance Schedules

The objective of this step is to develop a comprehensive schedule that considers all events that effect the manufacturing equipment. This schedule should include planned production time, scheduled downtime, provisions for unscheduled downtime, and research and development activities that utilize the equipment.

Task 13: Establish Reliability Engineering & Predictive Maintenance Practices

The goals of these functions are to determine the root causes of equipment problems and identify resources required to improve equipment reliability. The data collected for these functions can be used to develop predictive indicators of maintenance requirements, as well as provide feedback to equipment engineers and suppliers.

Task 14: Develop Equipment Design & Start Up Management Methods

The intent of this step is to utilize the knowledge gained through the TPM program to develop new manufacturing equipment that is easier to maintain. A process is also developed for introducing new manufacturing equipment into the workplace with minimal disruption. This allows for rapid ramp-up to full speed production use of new equipment.

Task 15: Hold the Gains

This is the final activity of the TPM Implementation Program. This activity is intended to continue the TPM Program into the incremental process improvement phase, using a Continuous Quality Improvement (CQI) approach. Once the above tasks have been completed and institutionalized, the team should continue to meet periodically to look for ways to improve upon their success.

Appendix C: Sample TPM Implementation Plan

The TPM implementation plan contained in this appendix provides a more detailed example of what is required to implement TPM into a small collection of manufacturing work cells. The following plans include some language that is specific to the FAIT group, which received this plan. This particular implementation plan is still not complete, since it has not been implemented and updated with lessons learned from the initial application. Developing an effective implementation plan should be viewed as an iterative process where the plans are updated as the team learns from using the plans.

This plan provides a step-by-step guide to introducing TPM into the workplace. It uses a staggered scheduling approach, which starts with the highest priority equipment, as determined by a cross functional team. The prioritization is based on equipment safety, reliability, quality, etc. Once the first implementation team is up and running, the next highest priority equipment will be targeted. The plan also uses the concept of 'natural work groups' for forming planning and implementation teams. The activities in this plan borrow heavily from the concepts of Total Quality Management (TQM) and Lean Manufacturing.

This implementation plan was prepared for the FAIT Program, however the scope of this plan can be expanded to include all of the 757 Fuselage MBU (or more). If the scope of the implementation is to be expanded, the only change required is that an even higher level management support team would be required. This higher level team would need to oversee the implementation in the various areas to assure consistency.

Goals

The following is a summary of the goals of this implementation plan:

1. Increase the amount of time that the production equipment is available for use
2. Reduce the amount of hardware variability in the parts produced
3. Reduce the number of accidents in the workplace
4. Encourage production mechanic ownership of, and responsibility for, their equipment
5. Establish metrics to allow data driven decisions

6. Provide factory production mechanic/equipment operator (user) ownership of this plan
7. Foster management support of this plan, and TPM in general
8. Raise the level of maintenance support for the equipment
9. Integrate manufacturing initiatives (TPM, 5-S/Housekeeping, HVC, Safety)
10. Improve the orderliness of the factory
11. Avoid the elimination of jobs
12. Minimize the negative impact of change on the affected individuals

Each task of the implementation effort will be described by providing the following information:

1. Goals of each task
2. Training required
3. Data collection requirements
4. Problem solving tools utilized
5. Team membership requirements
6. Team leader responsibilities (including what organization they should be from)
7. Activities to be performed
8. Time required to perform activities
9. Role of management

A summary of the participant's responsibilities is included at the end of this plan, as well as a listing of the reference material used.

Task 1: Determine TPM Program Scope: Form TPM Management Team

<u>Goals:</u>

To develop the initial scope of the TPM Program and provide the necessary support. Also, this team should feel a sense of ownership of the detailed implementation plans.

<u>Training required:</u>

Brief introduction to TPM, including how it supports the goals of manufacturing and facilities maintenance. This team should also be familiar with the concepts of World Class/Lean Manufacturing.

<u>Data required:</u> None

Problem solving tools utilized:

- Brainstorming (7 QC Tools)
- Pareto Analysis (7 QC Tools)

Team members:

- FAIT Program Manager
- FAIT Factory Manager
- FAIT Facilities Maintenance Manager
- FAIT Industrial Engineering (IE) Manager
- FAIT Tooling Manager
- FAIT Operation's Technology (MR&D) Manager

Team leader:

- FAIT Program Manager

Activities:

- Determine the scope of this implementation plan (what areas of shop will be affected)
- Develop initial TPM goals: safety, downtime, part quality, equipment capability, etc.
- Identify & appoint a TPM Coordinator to facilitate this implementation plan
- Provide the necessary resources for the required activities: team members, supplies, etc.
- Approve the roles & responsibilities of the TPM team members
- Have regular status reviews & periodically attend team meetings
- Add TPM metrics to individual performance management plans (milestones, defect levels, downtime targets, etc.)

Time required:

- 2 weeks for initial meetings (meeting 3 times, 2 hrs/mtg = 6 hours)
- On-going effort = 4 hours per month

Management role:

- Provide strategic direction and on-going support for this implementation plan and document TPM goals on business plans

Task 2: ***Develop TPM Implementation Priorities: Form TPM Planning Team***

Goals:

To develop the prioritized sequence of implementation of the TPM program. The information gathered during this step will reflect the state of the equipment 'before' the implementation of TPM.

Training required:

- Introduction to TPM (BTPM Training Material)
- Concepts of Lean Manufacturing (Hirano: JIT Manual)
- Total Quality Management (TQM) tools (Shiba: TQM)

Data required:

- Safety data (accidents), broken down by machine
- Equipment downtime: scheduled & unscheduled, along with the causes
- Production part quality rates (defects), and the equipment that produced these parts
- Production bottleneck locations
- Machine/process capability study results
- Overall Equipment Effectiveness (OEE) measurements
- 5-S level achieved in each manufacturing area

Problem solving tools utilized:

- Brainstorming (7 QC Tools)
- Pareto analysis (7 QC Tools)
- 9 step method for proactive improvement (Shiba: TQM)
- TPM implementation prioritization matrix (Welded Duct Center (WDC) Tools)

Team members:

- Factory production lead mechanic for FAIT manufacturing cells
- Facilities maintenance lead mechanic for FAIT equipment
- Tooling support lead
- Industrial engineering (IE) lead for FAIT area
- TPM Coordinator

Team leader:

- TPM Coordinator

Activities:

- Collect necessary data for creating prioritization matrix (WDC Tools)
- Develop implementation sequence based on prioritization of equipment
- Develop customer (user) requirements for TPM implementation (Shiba: TQM)
- Develop metrics that align user's requirements with goals of TPM (Shiba: TQM)
- Provided feedback to management on implementation planning status

Time required:

- 4 weeks (meeting twice per week, for 1 hour each time = 8 hrs/person; plus time for data collection)

Management role:

- Provide necessary personnel to participate on the team
- Attend weekly status reviews
- Provide necessary facilities & materials
- Put TPM metrics on individual performance management plans

Task 3: Implement TPM Program: Form TPM Implementation Team

Goals:

This team will create and implement the detailed functions of the TPM Program. The team should be composed of the individuals that will implement these detailed plans to help create a sense of ownership of the results.

Training required: (these will be provided on a JIT basis, prior to their utilization)

- Introduction to TPM (BTPM Training Material)
- Concepts of Lean Manufacturing (Hirano: JIT Manual)
- Total Quality Management (TQM) tools (Shiba)
- Autonomous maintenance training (BTPM Training Material)
- Lockout/tag/tryout safety training (BTPM Training Material)
- Cleaning is inspection training (BTPM Training Material)
- Visual management techniques (BTPM, Hirano)

- Hardware Variability Control (HVC) data collection (HVC Training Material)

Data required:

This will vary in each implementation task. See the following sections for the breakdown.

Problem solving tools utilized:

This will vary in each implementation task. See the following sections for the breakdown.

Team members:

- TPM Coordinator
- Factory mechanic that operates the equipment being converted to TPM operation
- Facilities maintenance mechanic that supports the equipment being converted to TPM operation
- Tooling support individual that supports the equipment being converted to TPM operation
- Industrial engineer that supports the equipment being converted to TPM operation
- Others will vary, depending on the implementation Task

Team leader:

This will vary in each implementation task. See the following sections for the breakdown.

Activities:

This will vary in each implementation task. See the following sections for the breakdown.

Time required:

This will vary in each implementation task. See the following sections for the breakdown.

Management role:

- Provide necessary personnel to participate on the team
- Attend periodic status reviews
- Provide necessary facilities & materials
- Put TPM metrics on individual performance management plans

Task 4: Introduction to TPM Training

Goals:

To provide motivation to the implementation team to improve their equipment, and give an overview of the components and activities of a TPM program. Also, this step will communicate the goals and metrics from the Management Team and Planning Team to the Implementation Team members.

Training required:

- Overview of TPM class (BTPM Training Material)

Data required:

- Results of Management Team's activities (scope, high level TPM goals)
- Results of Planning Team's activities (prioritized list of equipment & implementation matrix)
- Data for the equipment that was generated and used by the Planning Team

Problem solving tools utilized:

- Brainstorming (7 QC Tools)

Team members:

- See Task 3

Team leader:

- TPM Coordinator

Activities:

- Attend training sessions
- Relate information in training to their specific equipment by applying concepts

Time required:

- 1 week (2 meetings of 2 hours each, = 4 hrs/person)

Management role:

See Task 3

Task 5: Implement Lockout/Tag/Tryout Safety Procedures

Goals:

To establish a process that assures the safety of everyone involved in the maintenance of the equipment. This process is required by regulatory agencies (OSHA/WISHA) for TPM activities.

Training required:

- Lockout/tag/tryout class (BTPM Training Material)

Data required:

- Existing lockout procedures

Problem solving tools utilized:

- Brainstorming (7 QC Tools)

Team members:

- See Task 3
- Safety, Health, & Environmental Affairs (SHEA) representative

Team leader:

- Factory mechanic (equipment operator)

Activities:

- Attend the lockout/tag/tryout training
- Develop lockout diagram from area layout map
- Document Lockout process & procedures

Time required:

- 1 week (1 meeting of 2 hours, plus practice exercises = 4 hrs/person)

Management role:

See Task 3

Task 6: Establish 'Cleaning is Inspection' Techniques

Goals:

This step is intended to familiarize the operators with their equipment. It is the beginning of the transfer of knowledge from facilities maintenance to equipment operators. The equipment will receive extensive cleaning, and situations that make daily maintenance difficult will be identified during this step. This Task also incorporates the concepts seen in the 5-S's levels 1 through 3 activities.

Training required:

- Cleaning is inspection class (BTPM Training Material)
- How to write single point lessons (WDC Tools)
- How to use improvement bulletins (WDC Tools)
- 5-S Training (WCC Training Materials & Hirano: JIT Manual)

Data required:

- Existing 5-S plans & checklists
- Existing tooling support checklists
- Existing facilities maintenance checklists
- Area layout map

Problem solving tools utilized:

- Brainstorming (7 QC Tools)
- Pareto Analysis (7 QC Tools)
- 5-S level 1-3 criteria (WCC Training Materials & Hirano: JIT Manual)
- Single Point Lessons (WDC Tools)

Team members:

- See Task 3

Team leader:

- Factory mechanic

Activities:

- Attend necessary training
- Integrate all existing equipment checklists (eliminate redundancies & simplify)
- Develop checklists for daily, weekly, & monthly cleaning/inspections using single point lessons
- Determine responsibilities for these cleaning and inspection activities, based on TPM philosophy
- Hold an Accelerated Improvement Workshop (AIW) to perform initial cleaning
- Start performing daily, weekly, & monthly cleaning/inspection tasks
- Identify & eliminate causes of contamination (e.g. oil leaks) using improvement bulletins
- Identify & eliminate hard to reach & inspect places using improvement bulletins
- Identify & reduce causes of downtime (scheduled & unscheduled) using improvement bulletins
- Develop data collection processes to track improvements in downtime, efficiency, & quality

- Fill out Cleaning is Inspection exit criteria checklist (WDC Tools)
- Provide status/visibility of progress to management support team

Time required:

- 10-12 weeks (1/2 hour per day = 25-30 hrs/person, plus AIW time)

Management role:

- See Task 3
- Periodically walk through area to monitor progress & show support

Task 7: Implement Visual Controls

Goals:

The goal of this step is to develop a system of color coding, labeling, mapping, & standardizing that creates a common understanding of the workplace. These controls should easily distinguish between what is normal and what is not, make abnormalities and waste obvious enough for anyone to recognize, and constantly uncover needs for improvement. This step will achieve 5-S levels 4 & 5 for the workplace.

Training required:

- Visual Control training (BTPM Training Materials)
- 5-S training (WCC Training Materials & Hirano: JIT Manual)

Data required:

- Area layout maps (inspection routes from Task 6)
- Normal machine operating parameters (fluid levels, pressure gauge readings, etc.)
- Inspection checklists from Task 6

Problem solving tools utilized:

- Brainstorming (7 QC Tools)
- 5-S level 4 - 5 criteria (WCC Training Materials & Hirano: JIT Manual)

Team members:

- See Task 3

Team leader:

- Factory mechanic (equipment operator)

Activities:

- Determine appropriate locations for items stored in the workplace
- Mark these locations so that their absence is obvious (e.g. shadow boards, outline tape on floor)
- Determine proper settings on all gauges
- Mark these settings so that deviation from normal is obvious
- Identify inspection points on equipment and correlate with inspection checklists & area layout maps
- Check tightness on critical fasteners & match-mark fasteners with surrounding structure
- Hold an Accelerated Improvement Workshop (AIW) to perform initial labeling

Time required:

- 10 weeks (1/2 hour per day = 25 hrs/person, plus AIW time)

Management role:

- See Task 3
- Periodically walk through area to monitor progress & show support

Task 8: Standardize Lubrication Processes

Goals:

This step is intended to educate the team on the requirements for proper lubrication, and to develop standard methods for ensuring proper lubrication. The team will also look for opportunities to reduce the variety of lubricants required for the equipment. The amount of effort for this step will vary depending on the equipment.

Training required:

- Lubrication training (BTPM Training Materials)

Data required:

- Area layout maps (inspection routes from Task 6)
- Inspection checklists from Task 6
- Machine lubrication specifications
- Current data on lubrication frequency, type, and location

Problem solving tools utilized:

- Brainstorming (7 QC Tools)

Team members:

- See Task 3
- Facilities engineer (lubrication specialist)
- Op's Tech (Manufacturing Research & Development) engineer (lubrication specialist)

Team leader:

- Facilities maintenance mechanic/technician

Activities:

- Develop a lubrication checklist & integrate with cleaning/inspection checklist
- Create a lubrication route using the area layout map
- Color code lubrication points with the checklist and the lubrication storage containers
- Determine frequency of use for various lubrication types & consolidate the variety of lubricants
- Develop single point lessons for each lubrication process
- Develop data collection plan for determining lubrication frequency requirements

Time required:

- 4-10 weeks, depending on equipment (10 minutes per day, plus occasional meetings)

Management role:

- See Task 3
- Periodically walk through area to monitor progress & show support

Task 9: Perform Process Improvement Exercise

Goals:

This step provides an opportunity to reflect on the progress made so far and make necessary course corrections. This is the 'Check-Act' portion of the P-D-C-A cycle. The team will also quantify the benefits of implementing TPM by comparing current data to the original data collected for the prioritization planning team.

Training required:

- Plan - Do - Check - Act for Process Improvements (WCC Training Materials)

Data required:

- Original data used by the prioritization Planning Team
- Improvement bulletins that have been documented by the team
- Single Point Lessons that have been documented by the team
- Checklists & area layout maps that have been created by the team
- Data collection sheets that have been developed by the team
- Original goals & metrics from Management Team & prioritization Planning Team

Problem solving tools utilized:

- Brainstorming (7 QC Tools)
- Pareto analysis (7 QC Tools)
- Ishikawa (fishbone) diagram (7 QC Tools)
- Affinity diagram method (7 MP Tools)
- 7 Step reactive improvement method (Shiba: TQM)

Team members:

- See Task 3

Team leader:

- TPM Coordinator

Activities:

- Collect current data that is similar to original data collected by prioritization Planning Team
- Compare current data to original data & determine progress
- Develop improvement plans for metrics that have not see improvement
- Review improvements incorporated to date, and quantify benefits
- Analyze documented procedures, checklists, & lessons to identify opportunities for simplification
- Evaluate training provided & recommend improvements
- Based on results of this review, determine & document any necessary course corrections
- Provide feedback to management on implementation progress

Time required:

- 4-6 weeks (weekly meetings & occasional data collection)

Management role:

- See Task 3

Task 10: Finalize & Standardize Autonomous Maintenance

Goals:

This is the final step in the Autonomous Maintenance (AM) phase of TPM implementation. This step will stabilize and document the elements of AM, and integrate them with the existing manufacturing activities.

Training required:

- HVC data collection
- Overall Equipment Effectiveness (OEE) data collection & calculation (BTPM Training Materials)

Data required:

- HVC data collection plans for workplace
- Safety, Health, and Environmental Affairs (SHEA) requirements for workplace

Problem solving tools utilized:

- Brainstorming (7 QC Tools)

Team members:

- See Task 3
- Quality Assurance inspector (as required)
- SHEA representative (as required)

Team leader:

- Factory mechanic

Activities:

- Consolidate HVC data collection and cleaning/inspection & lubrication processes
- Consolidate SHEA procedures and cleaning/inspection & lubrication processes
- Document cleaning/inspection & lubrication processes using single point lessons

- Develop data collection sheets that allow calculation of OEE

Time required:

- 4-6 weeks (10 minutes per day, plus occasional meetings)

Management role:

- See Task 3

Task 11: Develop Preventive Maintenance Plans

Goals:

The goal of this step is to develop an equipment maintenance schedule for proactive/Preventive Maintenance (PM) activities. A method for managing the equipment spare parts inventory will also be developed. This requires understanding the equipment at the component level, as well as knowing the effects of equipment failure

Training required:

- Preventive maintenance training (BTPM Training Materials)
- Spare parts inventory management methods (Nakajima: Intro. to TPM)

Data required:

- Mean Time Between Failure (MTBF) data for equipment
- Mean Time To Repair (MTTR) data for equipment
- Calibration/Certification requirements for equipment

Problem solving tools utilized:

- Brainstorming (7 QC Tools)
- Ishikawa (fishbone) diagram (7 QC Tools)

Team members:

- See Task 3
- Facilities engineer
- Tool design engineer

Team leader:

- Facilities maintenance mechanic/technician

Activities:

- Establish priorities of PM tasks (e.g. safety issues, FAA requirement, OSHA requirement, etc.)
- Break equipment into individual component types for PM implementation plans
- Using historical data, determine frequency of periodic inspections (facilities maintenance tasks)
- Using historical data, determine accurate estimates of time required to perform inspections & repairs
- Perform machine/process capability studies to establish equipment performance capability
- Determine linkage between equipment performance parameters & resulting production part quality using Design of Experiments (DOE) techniques
- Using historical data and experimentation, establish thresholds of allowable equipment degradation
- Develop process for planned restoration of equipment deterioration
- Establish targets for improving MTBF & MTTR
- Develop data collection method for tracking spare part usage

Time required:

- 4-6 weeks (meeting twice per week, for 1 hour each time)

Management role:

- See Task 3

Task 12: Integrate Production and Maintenance Schedules

Goals:

The goal of this step is to develop a comprehensive schedule that considers all events that occur in the workplace that affect the production equipment availability. This schedule should include planned production time, research and test activities, scheduled downtime, and provisions for unscheduled downtime.

Training required: none

Data required:

- Production schedule for workplace

- Preventive Maintenance(PM) schedules, including estimates of planned downtime
- Autonomous Maintenance (AM) schedules (Cleaning/inspection, lubrication, & data collection)

Problem solving tools utilized:

- Brainstorming (7 QC Tools)

Team members:

- See Task 3

Team leader:

- Industrial engineer/production scheduler

Activities:

- Create list of typical activities occurring in workplace & their required time
- Overlay Production schedule, PM schedule, & AM schedule with hours currently available
- Incorporate provisions for PM schedule, AM schedule, & planned downtime into Production schedule
- Develop a simple process for linking Production & Maintenance schedules to avoid conflicts
- Evaluate workplace for opportunities to reduce cycle time (e.g. set-up time reduction)

Time required:

- 4 weeks (meeting twice per week, for 1 hour each time)

Management role:

- See Task 3

Task 13: Establish Reliability Engineering & Predictive Maintenance Practices

Goals:

The goals of this step are to determine the root causes of equipment problems and identify resources required to improve equipment reliability. The data collected can be used to develop predictions of maintenance requirements, as well as provide feedback to equipment engineers and suppliers.

Training required: none

Data required:

- Equipment downtime history, including causes of downtime
- Results of machine/process capability studies

Problem solving tools utilized:

- Brainstorming (7 QC Tools)
- Ishikawa (fishbone) diagram (7 QC Tools)

Team members:

- See Task 3
- Facilities Engineer
- Quality Engineer
- Process Engineer
- Op's Tech (MR&D) Engineer

Team leader:

- Facilities engineer

Activities:

- Identify and resolve root causes of chronic equipment problems
- Perform statistical analysis of maintenance data (downtime, repairs, etc.) to isolate problems and determine causal relationships
- Perform periodic vibration analysis studies to detect accelerated deterioration (as required)
- Perform periodic shock pulse studies to detect accelerated deterioration (as required)
- Perform periodic thermography studies to detect accelerated deterioration (as required)
- Perform periodic oil/lubricant analysis studies to detect accelerated deterioration (as required)
- Utilize results from above studies to develop models of equipment deterioration rates
- Based on deterioration models, optimize proactive replacement schedules for components

Time required:

- 2 weeks to develop data collection plan

Management role:

- See Task 3

Task 14: Develop Equipment Design & Start Up Management Methods

Goals:

The goal of this step is to utilize the knowledge gained through the TPM program to develop new manufacturing equipment that is easier to maintain. A process is also developed for introducing new manufacturing equipment into the workplace with minimal disruption and rapid ramp-up to full speed production use.

Training required: none

Data required:

- Chronic equipment failure data
- Equipment reliability data

Problem solving tools utilized: none

Team members:

- See Task 3
- Facilities Engineer
- Quality Engineer
- Process Engineer
- Op's Tech (MR&D) Engineer
- Facilities purchasing representative
- Equipment supplier representative

Team leader:

- Facilities engineer

Activities:

- Develop estimates of life cycle costs of existing equipment, and identify improvement opportunities
- Develop initial service requirements based on reliability data from similar equipment

- Develop implementation schedules, training requirements, and capability tests to be provided early in the acquisition process
- Provide data from chronic problems to equipment supplier to enable problem avoidance
- Include machine operators (factory mechanics) in evaluating potential equipment purchases
- Have equipment supplier incorporate visual control requirements on equipment prior to delivery
- Have equipment supplier incorporate set-up reduction concepts on equipment prior to delivery

Time required:

- 4 weeks to compile information for a supplier

Management role:

- See Task 3

Task 15: Hold the Gains

Goals:

The goal of this step is to continue the TPM Program into the incremental process improvement phase, using a Continuous Quality Improvement (CQI) approach. Once the above tasks have been implemented and institutionalized, the team should continue to meet periodically to look for ways to improve upon their success.

Training required:

- See all previous tasks

Data required:

- All data that is generated as part of the TPM Program

Problem solving tools utilized:

- Brainstorming (7 QC Tools)
- Pareto analysis (7 QC Tools)
- Ishikawa (fishbone) diagram (7 QC Tools)
- Affinity diagram method (7 MP Tools)

- 7 Step reactive improvement method (Shiba: TQM)

<u>Team members:</u>

- See all previous tasks

<u>Team leader:</u>

- TPM Coordinator

<u>Activities:</u>

- Return to 'Cleaning is Inspection' (Task 6) and look for improvement opportunities in the new processes
- Update repair time estimates, based on more recent performance data
- Document 'lessons learned' from the team's experience & provide this info to other TPM teams
- Provide feedback to management on implementation progress and lessons learned

<u>Time required:</u>

- Occasional meetings for the life span of the equipment (1 meeting every 2 weeks)

<u>Management role:</u>

- See Task 3
- Reward the efforts of the team

Roles & Responsibilities of Participants

The following is a summary to the primary responsibilities of each team member:

<u>FAIT Program manager:</u>

- Provide enthusiastic support of the planning & implementation teams
- Include high level TPM goals in individual performance management plans and business plans
- Attend status review meetings
- Allocate resources as necessary to support this implementation plan
- Incorporate appropriate improvement ideas developed by the implementation team

<u>Facilities maintenance manager:</u>

- See FAIT Program manager responsibilities

- Provide visibility of implementation progress to rest of facilities maintenance organization

Factory (shop) manager:

- See FAIT Program manager responsibilities
- Provide visibility of implementation progress to upper manufacturing management

Tooling support manager:

- See FAIT Program manager responsibilities
- Provide visibility of implementation progress to upper tooling management

Industrial engineering manager:

- See FAIT Program manager responsibilities
- Provide visibility of implementation progress to upper industrial engineering management

TPM Coordinator:

- Assist in the development and documentation of the implementation plan
- Facilitate the team meetings to ensure satisfactory progress
- Attend training sessions with management team, planning team, & implementation team
- Provide visibility of implementation progress to management

Employee Training & Development (ET&D) personnel:

- Provide necessary skills training
- Update training materials, based on feedback of team's process improvement activities
- Provide advance education to TPM Coordinator, to improve their ability to facilitate the teams

Factory lead mechanic:

- Share knowledge of manufacturing equipment, by participating on the Prioritization Team
- Support the activities of the factory mechanic/equipment operator assigned to the implementation team

Facilities maintenance lead mechanic/technician:

- Share knowledge of equipment maintenance, by participating on the Prioritization Team

- Support the activities of the facilities maintenance mechanic assigned to the implementation team

Tool support lead mechanic:

- Share knowledge of repairing and maintaining support tools, by participating on the Prioritization Team
- Support the activities of the tool support mechanic assigned to the implementation team

Industrial engineering lead engineer/technician:

- Share knowledge of scheduling production and maintenance tasks with the Prioritization Team
- Support the activities of the Industrial Engineer assigned to the implementation team

Factory mechanic/equipment operator:

- Lead the majority of the implementation efforts on the equipment in their workplace
- Prevent equipment deterioration by operating equipment correctly, cleaning and lubricating equipment
- Measure equipment deterioration by developing checklists and conducting daily inspections and data collection
- Restore equipment by assisting in equipment repairs and quickly reporting malfunctions accurately
- Assume responsibility and ownership of the manufacturing equipment in the workplace

Facilities maintenance mechanic/technician:

- Lead the TPM implementation team through the facilities maintenance tasks
- Provide training to operators on simple maintenance tasks, inspecting, cleaning, and lubricating
- Maintain equipment by performing periodic planned maintenance, preventive maintenance, and repairs
- Improve equipment by correcting equipment design weaknesses and incorporating reliability feedback
- Establish maintenance standards, keep maintenance records, and evaluate results of maintenance work

- Coordinate team's activities with other sections of the facilities maintenance organization

Tool support personnel:

- Ensure tool standards are supported by participating on the implementation team
- Provide feedback to tool design organization on improvement ideas created by the team
- Follow up on all tool revisions and design requests to ensure timely incorporation

Industrial engineering personnel:

- Provide implementation team with data on production bottlenecks and chronic scheduling problems
- Incorporate schedule revisions developed by the team

Operation's technology (MR&D) personnel:

- Provide technical expertise for machine capability studies, lubrication standards, etc.

Quality assurance personnel: (QA inspector & Quality Engineer)

- Provide team with data on production part quality and customer feedback
- Assist team with integration of production part variation data into inspection routines

Facilities maintenance engineering personnel:

- Provide feedback to equipment manufacturers on Design for Maintenance concepts

Manufacturing engineering personnel: (Production Planner & Process Engineer)

- Incorporate relevant improvement ideas into production plans

References

7 QC Tools *The Memory Jogger.*

also see Shiba, Shoji, Graham, Alan, & Walden, David. *A New American TQM: Four Practical Revolutions In Management.* Portland, OR: Productivity Press, 1993.

7 MP Tools *The Memory Jogger Plus +.*

also see Shiba, Shoji, Graham, Alan, & Walden, David. *A New American TQM: Four Practical Revolutions In Management.* Portland, OR: Productivity Press, 1993.

BTPM Boeing Total Productive Maintenance Training Material. Developed by Don Peterson, et al.

Hirano Hirano, Hiroyuki. *JIT Implementation Manual.* Portland, OR: Productivity

Press, 1993.

Nakajima Nakajima, Seiichi. *TPM Development Program.* Cambridge, MA: Productivity Press, 1989.

Shiba Shiba, Shoji, Graham, Alan, & Walden, David. *A New American TQM: Four Practical Revolutions In Management.* Portland, OR: Productivity Press, 1993.

WCC Boeing Training Material. *Managing for World Class Competitiveness.* Developed by Delta Point Corp.

WDC Welded Duct Center Training Material. Developed by Pauline Marshall, et al.