Maintenance and Reliability Best Practices

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Preface

Purpose of the book

In today's global economy, we are facing two major challenges:

- Competitiveness
- Lack of skilled work force

Producing quality products or providing services at competitive prices is essential for surviving in today's business climate. We are forced to look for better ways of doing things on continual basis. Satisfying customers' needs — on their schedule — requires (high) availability and reliability of equipment and systems. We in the maintenance and reliability (M&R) field are constantly challenged to implement the best way to ensure equipment is available when we need it at a reasonable cost. We have come to call these our "best practices." But it is not as simple as putting something into effect. Truly implementing a best practice requires learning, relearning, benchmarking, and realizing better ways of ensuring high reliability and availability of equipment and systems. This book is designed to support that learning process of implementing best practices in maintenance and reliability.

Implementing best practices for achieving the optimal reliability and availability of equipment at the optimal cost requires a work force with a thorough understanding and knowledge of both M&R principles and available technologies. When we say "work force," we mean literally everyone. These include designers who design the equipment; operators who operate; and maintainers who maintain; warehouse and store personnel who procure and supply materials; engineers who improve the reliability; and human resource professionals who provide and arrange for a work force. Achieving high reliability and availability requires teamwork.

Although there are many books available in this field, most of them are focused on a specific practice, e.g., Reliability-Centered Maintenance (RCM), Total Productive Maintenance (TPM), Benchmarking, Lean Maintenance, and Performance Measurements. This book takes a more basic approach. It provides an overview of key best practices, how to implement them and measure their effectiveness, and offers the best M&R

practices to expand understanding of M&R to everyone currently or looking to be in the work force of an organization.

Readers of the book

Maintenance (M) is concerned with maintaining assets through the use of proactive and corrective maintenance techniques combined with how quickly equipment can be returned to operating condition after it has failed. Improving maintenance is a tactical task.

Reliability (R) is concerned with predicting and preventing failures to ensure assets will perform to their required or designed functions. Improving reliability is a strategic task.

Both tactical and strategic tasks cost money, which is usually limited in M&R management. Therefore, understanding and implementing M&R practices in a cost-effective way becomes essential. The key objective of this book is to provide basic understanding of M&R "best practices," whether to a novice or to a seasoned professional. As the saying goes, "Give a man a fish and feed him for a day. Teach a man to fish and feed him for a lifetime." This philosophy has been a guide in writing this book.

The book is written to teach M&R "best practices" in an easy-to-understand format designed to benefit the reader. It's organized in 12 chapters, each covering key areas and practices in the M&R field. Each topic answers the what, why, or how of the principles and technique being presented. Most of the chapters are organized as:

- Chapter overview
- Key terms / definitions
- Chapter content / discussion
- Summary
- References and suggested reading

In addition, several chapters provide possible real-world scenarios to make the ideas and application useful and easier to understand.

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Chapter 1

Introducing Best Practices

I have not failed. I have found 10,000 ways that won't work.
— Thomas Edison

After reading this chapter you will be able to understand

- What are best practices and why are they best practices?
- The objective of maintenance and reliability
- Why we need to focus on reliability
- Key Maintenance and Reliability (M&R) terms and benchmark examples

In addition, you also able to test your knowledge in basics of Maintenance and Reliability by taking a short test.

1.1 What Is a Best Practice?

The notion of a best practice is not new. Frederick Taylor, the father of modern management, said nearly 100 years ago, "Among the various methods and implements used in each element of each trade, there is always one method and one implement which is quicker and better than any of the rest." In recent times, this viewpoint has come to be known as the "one best way" or "best practice."

"Best practice" is an idea which asserts that there is a technique, method, or process that is more effective at delivering a desired outcome than any other technique, method, or process. The idea is that with this technique, a project or an activity such as maintenance can be completed with fewer problems and unforeseen complications. Simply, we can say that a technique, practice, method, or process may be deemed a "best practice" when it produces superior results. Usually it is a documented practice used by the most respected, competitive, and profitable organizations. A best practice, when implemented appropriately, should improve performance and efficiency in a specific area. We also need to understand that "best practice" is a relative term. To some it may be a routine or a standard practice; but to others, it may be a best practice because a current practice or method is not effective in producing the desired results.

History is filled with examples of people who were unwilling to accept or adopt the industry standard as the best way to do anything. The enormous technological changes since the Industrial Revolution bear witness to this fact. For example, at one time horses were considered the best form of transportation, even after "horseless carriages" were invented. Today, most people drive a gasoline or diesel vehicle — all improvements on the original horseless carriage. Yet concerns over oil costs, supplies, and global warming are driving the next set of transportation improvements.

In the 1968 Summer Olympics, a young athlete named Dick Fosbury revolutionized the high-jumping technique. Using an approach that became known as the Fosbury Flop, he won the gold medal by going over the bar back-first instead of head-first. Had he relied on "standard practice," as did all of his fellow competitors, he probably would not have won the event. Instead, by ignoring standard practice, he raised the performance bar — literally — for everyone. The purpose of any standard is to provide a kind of reference. Therefore, that standard must be, "what is possible?" and not, "what is somebody else doing?"

In real-world applications, best practice is a very useful concept. Despite the need to improve on processes as times change and things evolve, best practice is considered by some as a business buzzword used to describe the process of developing and following a standard way of doing activities that any organization can use or implement to get better results. Implementing best practice in the area of maintenance and reliability can help an organization to:

- Increase output with the same assets
- Reduce the need for capital replacement
- Reduce maintenance cost per unit
- Reduce total cost per unit
- Improve performance — cost, productivity, and safety
- Increase competitiveness
- Increase market share

A best practice tends to spread throughout an industry after a success has been demonstrated. However, demonstrated best practices can be slow to implement, even within an organization. According to the American Productivity and Quality Center, the three main barriers to adoption of a best practice are a lack of:

1. Knowledge about current best practices,
2. Motivation to make changes for their adoption
3. Knowledge and skills required to do so.

The objective of this book is to provide knowledge of best practices in the areas of maintenance and reliability, and to implement best practices effectively. In later chapters, we will be discussing what we can do to eliminate these barriers to create a sustainable reliability culture in an organization.

1.2 Understanding Maintenance and Reliability

In any organization, assets are needed to make products or to provide services. The objective of maintenance and reliability in an organization is to ensure that the assets are available, when needed, in a cost effective manner. The performance of an asset is based on three factors (see Figure 1.1):

- Inherent reliability — how it was designed
- Operating environment — how it will be operated
- Maintenance plan — how it will be maintained

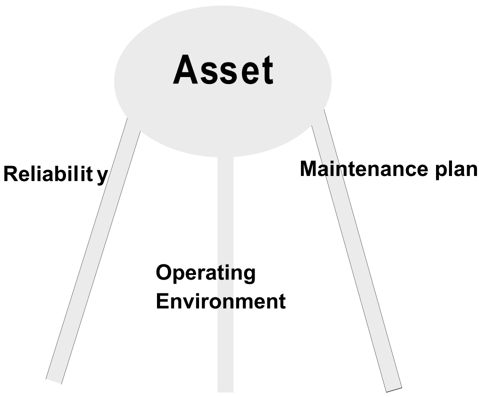

Figure 1.1
Asset Performance

Usually assets are designed with a certain level of reliability. This designed-in (or built-in) reliability is the result of individual components' reliability and how they are configured. This level of reliability is called inherent reliability. We can not change or improve reliability of an asset after it has been installed without replacing with better and improved components or redesigning.

The second factor, the operating environment, considers operating conditions under which the asset has to operate and the operator's skills. Several studies have indicated that 40% or more of failures are the result of operational errors. Organizations need to ensure that operators are appropriately educated and trained in operating the asset without any operational errors causing failures. In fact, operators should be the first line of defense in watching for an asset's abnormal conditions and in initiating corrective actions.

The third factor is a maintenance plan that will define how the asset will be maintained. The objective of the maintenance plan is to sustain asset reliability and to improve its availability. The plan should include the necessary maintenance and service-type actions needed to detect potential failures before they create unscheduled downtime. We will be discussing these factors and what best practices could be implemented to improve asset performance throughout this book

Reliability, a design attribute, is a broad term that focuses on the ability of an asset (product) to perform its intended function. As defined in military standard MIL-STD-721C, reliability is "the probability that an item will perform its intended function for a specific interval under stated conditions."

An item or asset, as defined here, could be an electronic or mechanical hardware component or device, a software product, or a manufacturing system or process.

David L. Stringer, Brig. Gen, USAF (ret.), speaking at the RCM/EAM 2006 Conference, introduced a new definition of reliability. He said reliability is "the achievement of predictable results with as little variation as specific circumstances permit."

Maintainability is another design attribute that goes hand in hand with reliability. The objective of maintainability is to ensure maintenance tasks can be performed easily and effectively. Basically, it is ease of maintenance.

There are a number of reasons why reliability and maintainability are important asset (product) attributes, including:

- Reputation — highly reliable assets are dependable and, if they fail, they can be fixed quickly
- Customer satisfaction — reliable assets produce quality products and support in meeting customer's schedule
- Repeat business — resulting from above factors
- Competitive advantage — reduced cost

A reliable plant means that the plant and its assets are available, as and when needed, to meet customer's needs on schedule and at cost.

On the other hand, maintenance is an act of maintaining, or the work of keeping an asset in proper operating condition. It may consist of performing maintenance inspection and repair to keep assets operating in a safe manner to produce or provide designed capabilities. These actions can be preventive maintenance (PM) and corrective maintenance (CM) actions. So, maintenance keeps assets in an acceptable working condition, prevents them from failing, and, if they fail, brings them back to their operational level effectively and as quickly as possible.

The reliability and maintainability attributes are usually designed into the assets, which minimize maintenance needs by using reliable components that are easy to repair, if and when needed. An optimized Preventive Maintenance (PM) plan is developed using reliability principles and techniques such as Failure Mode and Effects Analysis (FMEA) and Reliability Centered Maintenance (RCM) as well as wider use of Condition Based Maintenance (CBM) and Predictive Maintenance (PdM) technologies.

1.3 Examples of Maintenance and Reliability Benchmarks

What are the best practices in the maintenance and reliability (M&R) area and how could those be implemented to get better results? M&R best practices are practices that have been demonstrated by organizations who are leaders in their industry. These companies are the quality producers with very competitive cost, usually the lowest in their industry. They are also are known to have the lowest maintenance cost as a percentage of replacement asset value (RAV). A few examples of maintenance and reliability best practices benchmarks are listed in Figure 1.2.

Best of the Best	Best Practice Benchmark	Typical World Class
Maintenance Cost as a percent of RAV (RAV — Replacement Asset Value)	3–9%	2.5–3.5%
Maintenance Material Cost as a percent of RAV	2–4%	0.25–0.75%
Schedule Compliance	30–50%	> 90%
Percent (%) Planned work	10–40%	> 85%
Production Breakdown Losses	5–12%	1–2%
Parts Stockout Rate	5–10%	1–2%

Figure 1.2 Comparing Best Practices Benchmark

In Table 1.2, Maintenance Cost as a Percentage of Replacement Asset Value (RAV) is used as a benchmark for best practices. We can immediately identify the cost differences between companies that are Typical and World Class or Best in Class. However, typical companies should be spending more money in maintenance as they build their maintenance and reliability program. Then, once they have achieved a desired level of reliability and availability, they should be able to reduce the maintenance cost by continuing to apply the best practices. Note that these benchmarks are not inclusive.

We need to be very diligent in using these benchmarks because definitions of these benchmarks vary a lot from one organization to another. When we use these benchmarks and compare with others, it's important that terms used by the two organizations are the same. For example:

1. Maintenance Cost as a percent of RAV: This measure is calculated as maintenance cost divided by the replacement asset value. In this benchmark, two factors must be defined in order to ensure a comparison is accurate:

a. Maintenance cost. This factor is the cost of maintenance for a plant or facility; it includes maintenance labor, maintenance materials, contractors used to perform maintenance work, capital maintenance, and the cost of all projects to replace worn out assets.

b. Replacement Asset Value (RAV). This number typically comes from the engineering or company's insurance carrier and not from accounting. It is not book value. Instead, it is the current replacement cost of all assets for an industrial facility. This measure should include the cost of removing old assets and the cost of installing new ones.

2. Maintenance Material Cost as a Percent of RAV: This benchmark is calculated as maintenance material cost divided by the replacement asset value. In most organizations, the material cost is easier to obtain from the Computerized Maintenance Management System (CMMS) or organization's financial system. To ensure a comparison is accurate, we must ensure that the maintenance cost includes all maintenance material purchased for all assets in a plant, including maintenance storeroom parts and material, parts and material used by contractors on maintenance, and capital maintenance work.

For example, organization "A" typically has their Maintenance Material Cost as 2% of RAV and organization "B," which has applied best practices, typically has their Maintenance Material Cost as 0.5% of RAV. This comparison indicates that organization "A" is spending four times for maintenance material compared to organization "B."

Caution: Organizations need to understand that neither maintenance cost nor maintenance material cost can be reduced in a sustainable manner without the application of best practices. Many organizations focus on maintenance cost reduction, but this approach has never worked without changing or improving processes, or applying best practices.

3. Schedule Compliance: This measure is the ratio of maintenance labor hours consumed for the jobs or tasks completed (which were on an approved schedule) divided by the total maintenance labor hours available during that period. Some organizations also track the number of jobs/tasks completed which were on an approved schedule versus the total jobs/tasks on a schedule.

a. Maintenance Schedule. The maintenance schedule identifies jobs/tasks to be completed and approved in the previous week or at least three days in advance. It should cover 100% of maintenance labor.

For example, organization "A" is typical; their schedule compliance is 40%. Organization "B" has applied best practices and has a schedule compliance of 80%. This comparison indicates that organization "B" is actually getting twice as much scheduled work out of its maintenance staff as organization "A." When schedule compliance is high, we usually find that organizations also have high uptime and asset utilization rates. There is a direct correlation between them.

4. Percent of Planned Work: This measure calculates the percent of maintenance work orders where all parts, material, specifications, procedures, tools, etc., have been defined prior to scheduling the work. This best practice is key to long-term success of any successful maintenance organization.

For example, a typical organization "A" has a percent of planned work measured at 10% whereas organization "B" has a percent of planned work measured at 90%. This comparison indicates that the organization "B" is proactively planning nine times more work and also they have high uptime and asset utilization rate. Their maintenance cost is also low as we know that unplanned work costs more to execute.

5. Production/Operations Breakdowns Losses: This number becomes small and insignificant as best practices are applied and become a normal way of life. One important issue which directly impacts this benchmark is that all personnel from the executive level to production operator must be responsible for the plant's assets. The organization management must support the journey to excellence in implementing best practices. Operators must see assets as something they own which will impact their lives in a positive manner. The only way this transformation can occur is through education and empowerment.

6. Parts Stockout Rate: This measure is based on the number of times a maintenance craft person visits the storeroom to get the parts needed versus when parts are supposed to be in the storeroom, but is not available in stock.

In working with many organizations over the years, we've noted that benchmarking is not an easy process, particularly when there are no standard definitions of terms to benchmark. For example, RAV (replacement asset value) may not have same meaning to Organizations A and B. Both of them may have different definitions. This problem has been a major challenge in M&R-related benchmarking initiatives. The Society for Maintenance and Reliability Professionals (SMRP) has taken the lead toward standardized maintenance and reliability terms, definitions, and metrics. Visit www.smrp.org to get additional information on standardized maintenance and reliability terms and definitions, including metrics.

When measuring against known benchmarks of best practices, one will find that all benchmarks are interconnected and interdependent. This is why an organization must have a defined maintenance and reliability process in order to implement best practices. Also, tailoring of a best practice to meet your environment and need is essential for an effective implementation.

So far, we have discussed just a few examples of best practices and their benchmarks. Throughout this book, we will be discussing practices which may be standard, good, or best depending upon where you stand in your journey to excellence in maintenance and reliability.

1.4 Basic Test on Maintenance and Reliability Knowledge

Many maintenance and reliability practitioners have not been successful in implementing best practices. Perhaps this is due to lack of or limited understanding of best practices or they were unable to get their management support. Take this test on the following pages to see where you stand in your reliability journey and in applying best practices.

Once you complete the test, go to Appendix A and score yourself appropriately. Do not guess on any of the questions. If you are uncertain, skip the question; otherwise, your results may give you a false sense of "best practices" knowledge.

1. Best Practices are practices that are defined and applied by an organization. They may or may not be proven, but results are found to be acceptable.
   a. True
   b. False

2. Maintainability is measured by PM schedule compliance.
   a. True
   b. False

3. All maintenance personnel's time is covered by work orders.
   a. True
   b. False

4. Operations and Maintenance work as a team to achieve improved OEE.
   a. True
   b. False

5. Best practices would indicate that 90% or more of all maintenance work is planned.
   a. True
   b. False

6. 100% of PM and PdM tasks should be developed using FMEA /RCM methodology.
   a. True
   b. False

7. Utilization of Assets in a world–class facility should be above 98%.
   a. True
   b. False

8. 100% of maintenance personnel's (craft) time should be scheduled.
   a. True
   b. False

9. Time-based PMs should be less than 20% of all PMs.
   a. True
   b. False

10. The 10% rule of PM is applied on critical assets.
   a. True
   b. False

11. Most emergency work orders should be written by production.
   a. True
   b. False

12. It is a common practice for Operators to perform PMs.
   a. True
   b. False

13. P-F interval can be applied to visual inspections.
   a. True
   b. False

14. Understanding of a P-F curve should help in optimizing PM frequency.
   a. True
   b. False

15. The best method of measuring the Reliability of an asset is by counting downtime events.
   a. True
   b. False

16. The primary purpose of scheduling is to coordinate maintenance jobs for greatest utilization of the maintenance resources.
   a. True
   b. False

17. What percentage of your assets should be ranked critical based on the risk to business?
    a. Less than 20%
    b. 20–50%
    c. over 50%

18. Vibration monitoring can detect uniform impeller wear.
    a. True
    b. False

19. Understanding the known and likely causes of failures can help design a maintenance strategy for an asset to prevent or predict failure.
    a. True
    b. False

20. Reliability can be improved easily after a maintenance plan has been put into operation.
    a. True
    b. False

21. What percentage of maintenance work should be proactive?
    a. 100%
    b. 85% or more
    c. 50%

22. MTBF is measured by operating time divided by the number of failures of an asset.
    a. True
    b. False

23. Maintenance cost will decrease as reliability increases.
    a. True
    b. False

24. The “F” on the P-F Interval indicates that equipment is still functioning.
    a. True
    b. False

25. A rule of thumb is that, on average, an experienced planner can plan work for how many craft people?
    a. 10
    b. 15
    c. 20 or more

26. Which of the following is not a primary objective for implementing Planning and Scheduling?
    a. Reduce reactive work
    b. Prevent delays during the maintenance process
    c. Mesh the production schedule and the maintenance schedule

27. The best method of measuring the reliability of an asset is by
    a. MTTR
    b. MTBF
    c. Both

28. With the exception of emergency work orders, P&S will benefit all maintenance work
    a. True
    b. False

29. Leading KPIs predict results.
    a. True
    b. False

30. The 6th S in the 6 S (also called 5 S plus) process stands for safety.
    a. True
    b. False

31. RCM stands for:
    a. Regimented Centers of Maintenance
    b. Reliability Centered Maintenance
    c. Reliable Centers of Maintenance (uses best practices)

32. The objective of RCM is to preserve functions.
    a. True
    b. False

33. An MRO storeroom shouldn’t be stocking parts for emergencies.
    a. True
    b. False

34. The inventory turnover ratio for MRO store should be
    a. Less than 2
    b. Between 4–6
    c. Over 6

35. PM compliance is a lagging KPI.
    a. True
    b. False

36. Quality is one key component of OEE.
    a. True
    b. False

37. Reliability and Maintainability can only be designed in.
    a. True
    b. False

38. Creating a reliability culture from a reactive mode can be accomplished in a short period of time if enough resources are made available.
    a. True
    b. False

39. Karl Fischer's Coulometric Titration Method is an effective tech nique to determine the metallic content (in PPM) in an oil sample.
    a. True
    b. False

40. An IR thermography window is an effective method to satisfy NFPA 70E arc flash requirements.
    a. True
    b. False

41. FMEA is applicable only to assets currently in use.
    a. True
    b. False

42. RCM methodology can't be used effectively on new systems being designed.
    a. True
    b. False

43. Properly training the M&R workforce can increase asset and plant availability.
    a. True
    b. False

44. TPM is a type of maintenance performed by the operators.
    a. True
    b. False

45. Lagging KPIs are the results of a process.
    a. True
    b. False

46. EOQ improves the inventory turn ratio.
    a. True
    b. False

47. New incoming oil from the supplier is always clean and ready to be used.
    a. True
    b. False

48. Which phase of asset life cycle has the highest cost?
    a. Design
    b. Acquisition
    c. O & M

49. Most of the maintenance costs are fixed
    a. After installation
    b. During operations
    c. During design

50. RCM provides best results when used
    a. During Operation /Production
    b. During Design / development
    c. After asset has failed or keeps failing

51. How soon we can restore an asset is measured by
    a. MTBF
    b. MTTR
    c. MTBMA
    d. None of the above

52. Availability is a function of
    a. MTBF
    b. MTTR
    c. Uptime
    d. Uptime and downtime

53. The failure rate of a component / asset can be calculated by knowing
    a. Number of failures
    b. MTBF
    c. MTTR
    d. Uptime

54. Most benefit of a Failure Mode and Effect Analysis occurs during
    a. Operations phase
    b. Maintenance phase
    c. Design phase
    d. None of the above

55. PM schedule compliance should be equal or greater than 95%.
    a. True
    b. False

Please go to Appendix 1-A on page 401 to check the best answers to these questions. If your correct answers are:

50 or more.	You have excellent M&R knowledge, but continue to learn and enhance your knowledge.
41–49.	You have good M&R knowledge, but there is a potential for improvement.
40 or less correct.	You have a lot of opportunities to improve.

1.5 Key Terms and Definitions

Annual Maintenance Cost as a Percent of Replacement Asset Value.

The amount of money annually spent to maintain assets, divided by the Replacement Asset Value (RAV) of the assets being maintained, expressed as a percentage.

Availability.

The probability that an asset is capable of performing its intended function satisfactorily, when needed, in a stated environment. Availability is a function of reliability and maintainability.

Failure Modes and Effects Analysis (FMEA).

A technique to examine an asset, process, or design to determine potential ways it can fail and the potential effects; and subsequently identify appropriate mitigation tasks for highest priority risks.

Maintenance and Reliability Best Practices.

These are maintenance and reliability practices which have been demonstrated by organizations who are leaders in their industry. These organizations are the quality producers with competitive prices in their industry.

Mean Time Between Failures (MTBF).

MTBF is the average length of time between one failure and another failure for an asset or component. MTBF is usually used for repairable assets of similar type. Another related term — Mean Time to Failure (MTTF) — is usually used for non-repairable assets i.e., light bulbs, rocket engines. Both terms are used as a measure of asset reliability. These terms are also known as mean life. MTBF is the reciprocal of the Failure Rate (Ï).

Mean Time To Repair (MTTR).

MTTR is the average time needed to restore an asset to its full operational capabilities after a failure. MTTR is a measure of asset maintainability.

MRO Inventory Value as a Percent of Replacement Asset Value (RAV).

The value of maintenance, repair, and operating materials (MRO) and spare parts stocked on site to support maintenance, divided by the Replacement Asset Value (RAV) of the assets being maintained at the plant, expressed as a percentage.

MRO Stores Inventory Turns.

Inventory turns identify how quickly specific types of inventory are flowing through the inventory system. Normally, this is divided into at least two categories: 1) operating supplies that are supposed to turn frequently; and 2) spare parts which will usually have a lower turnover.

PercentPlanned Work.

The amount of planned maintenance work that was completed versus the total maintenance hours available.

P&S.

Planning and Scheduling

Predictive Maintenance (PdM).

An equipment maintenance strategy based on 1) measuring the condition of equipment in order to assess whether it will fail during some future period and then 2) taking appropriate action to avoid the consequences of that failure. The condition of equipment could be measured using condition monitoring, statistical process control, or equipment performance, or through the use of the human senses. The terms Condition Based Maintenance (CBM), On-Condition Maintenance, and Predictive Maintenance are used interchangeably.

Preventive Maintenance (PM).

An equipment maintenance strategy based on inspection, component replacement, and overhauling at a fixed interval, regardless of its condition at the time. Usually scheduled inspections are performed to assess the condition of an asset. Replacing service items — e.g., filters, oils, and belts — and lubricating parts are a few examples of PM tasks. PM inspection may require another work order to repair other discrepancies found during the PM in a scheduled outage.

Proactive Work.

The sum of all maintenance work that is completed to avoid failures or to identify defects that could lead to failures (failure finding). It includes routine preventive and predictive maintenance activities and work tasks identified from them.

Reliability.

The probability that an item will perform its intended function for a specific interval under stated conditions.

Reliability Centered Maintenance (RCM).

A systematic and structured process to develop an efficient and effective maintenance plan for an asset to minimize the probability of failures. The process insures safety and mission compliance.

Schedule Compliance.

A measure of adherence to the maintenance schedule. It is usually computed on either a daily or a weekly basis, and is based on hours. Sometimes it is calculated as the ratio of the number of jobs/tasks completed verses total jobs/tasks on an approved schedule.

1.6 Summary

A best practice is a technique or methodology that, through experience and research, has proven to lead reliably to a desired result. When implemented appropriately, a best practice should improve performance and efficiency in a specific area. Understand that best practice is a relative term. A practice may be routine or standard to some, but to others, it may be a best practice because their current practice or method is not effective in producing the desired results.

A best practice is often not what everyone else is doing, but is what is possible to achieve. It requires persuasive techniques that rely more on appeals rather than force. A best practice is usually requires a change in process; thus, it need to be accepted by all for successful implementation.

Reliability and maintainability are important asset attributes. They are usually designed into the assets to minimize maintenance needs by using reliable components that are easy to repair if they fail. Some of the best practices — such as an optimized Preventive Maintenance (PM) plan — are developed using reliability principles and techniques such as Failure Mode and Effects Analysis (FMEA) and Reliability Centered Maintenance (RCM) as well as wider use of Condition Based Maintenance (CBM) and Predictive Maintenance (PdM) technologies.

A best practice tends to spread throughout an industry after a success has been demonstrated. However, demonstrated best practices can often be slow to implement, even within an organization. According to the American Productivity and Quality Center, the three main barriers to adoption of a best practice are a lack of:

1. Knowledge about current best practices
2. Motivation to make changes for their adoption
3. Knowledge and skills required to do so

The work force needs to have the knowledge of best practices in the area of maintenance and reliability so that they can implement them effectively. A commitment to using the best practices in the M&R field, utilizing all the knowledge and technology at one's disposal, ensures success.

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* SMRP — Society for Maintenance & Reliability Professionals
** IMC — International Maintenance Conference

Chapter 2

Culture and Leadership

Effective leadership is putting first things first.
Effective management is discipline, carrying it out.
—- Stephen Covey

After reading the chapter you will be able to understand:

- Organizational culture
- Leadership and its role
- Vision, mission, and goals
- Reliability culture

2.1 Introduction

Successful implementation of a new practice, small or large, is a challenge for any organization. The implementation requires enthusiasm rather than distrust or fear from the individuals who will be impacted by the change. Guiding, nurturing, and shepherding the work force are the skills needed to ensure that changes are received and implemented with a positive attitude. Usually, how the work force perceives these changes, their beliefs, values, attitudes, and expectations are a few of the factors that need to be evaluated and considered in developing a "change" implementation plan.

The vision of where the organization wants to be is an important element of creating a reliability culture. Steven Covey, the leading motivational author, emphasizes the importance of mission, vision statement, and goals when he talks about "beginning with the end in mind" in his famous best seller, *7 Habits of Highly Effective People.* Organizations using mission and vision statements successfully outperform those that do not by several times, according to a study done by a Stanford Management professor, as reported in *The Wall Street Journal.* When we visualize, we are able to materialize and convert our vision into goals and then into reality.

Leadership plays a key role in enabling this process by providing both direction and resources. Creating a reliability culture conducive to change is a long journey. It is not just the maintenance work force that needs to change their thinking, but also others in the organization, including operations, production, design, stores, and information technology departments. All need to be together as a team to create a sustainable reliability culture.

All organizations want to improve their processes in order to become efficient and effective. For maintenance and reliability (M&R) organizations, progress requires eliminating or reducing failures, while optimizing and educating the work force to perform their tasks effectively.

These efforts could require changes in work practices, processes, and organization structure. Eventually these changes become part of daily work habits in the organization and lead to a positive reliability culture.

Leadership creates vision and energizes people to make organizations and people successful. Figure 2.1 shows the results of a survey ranking five key attributes of leadership.

1. Charisma
2. Competence

3. Communication
4. Energizing people
5. Vision (in creating)

Leadership plays an important role in creating vision and energizing the work force, as reported by this survey. One of the important factors impeding success in an organization is lack of or not enough leadership support to implement changes. It has been found that successful leaders share a number of qualities needed to improve their processes. They support:

- Creating the organization's vision and mission
- Ensuring resource availability
- Empowering line managers with authority and accountability
- Ensuring an individual's and a group's goals are aligned with the organization's vision and goals
- Viewing training as an investment in developing the work force rather than an unnecessary expense

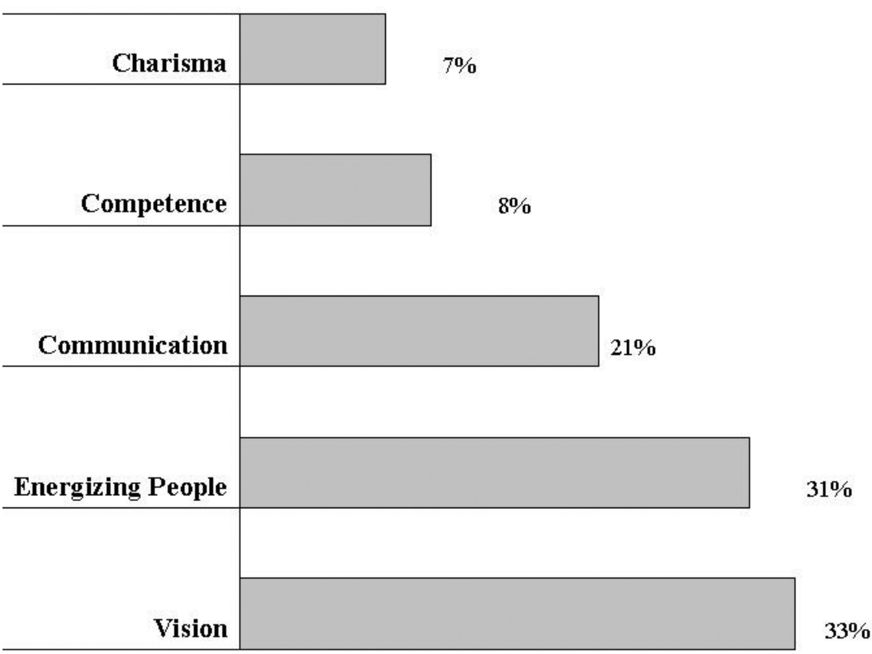


Figure 2.1

- Aligning and integrating all changes and processes improvements (the best practices) towards meeting the organization's overall objectives.

Leadership is a key enabler in creating an environment to implement reliability strategies, which helps in fostering a "reliability" culture in the long run.

True leadership is uncommon in today's society and organizations because it is not genuinely understood. Furthermore, it has been misinterpreted, according to James McGregor Burns, author of the book, *Leadership*. He wrote in this landmark book that:

Leadership is leaders inducing followers to act for certain goals that represent the values and the motivations — the wants and needs, the aspirations and expectations — of both leaders and followers. And the genius of leadership lies in the manner in which leaders see and act their own and their followers' values and motivations.

Donald Phillips, the author of Lincoln on Leadership — Executive Strategies for Tough Times, points out the following of Lincoln's principles on leadership.

- Get out of the office and circulate among the troops
- Build strong alliances
- Persuade rather than coerce
- Honesty and integrity are the best policies
- Never act out of vengeance
- Have courage to accept unjust criticism
- Be decisive
- Lead by being led
- Set goals and be results-oriented
- Encourage innovations
- Preach a VISION and continually reaffirm it

In modern days, Lincoln's principle of "Get out of the office and circulate among the troops" is known to us as Management by Wandering Around (MBWA), as dubbed by Tom Peters and Robert Waterman in their 1982 book, In Search of Excellence. The principle has also been referred to us by other names and phrases, such as "roving leadership," "being in touch," and "get out of the ivory tower." It is simply the process of getting out of the office and interacting with people. Peters and Nancy Austin, in A Passion for Excellence, define MBWA as “the technologies of the obvious.”

Leaders emerge in every life situation to guide others along a particular path of change and toward a final destination point. Effective leadership is not easy. History has shown us that the responsibilities and hazards of leadership are as great as its rewards. Recent studies in the field of leadership recognize and stress the need for building strong interpersonal relationships and bonds. In their book, Leaders, Warren Bennis and Burt Nanus note that “leadership establishes trust, leaders pay attention; they have the ability to trust others even if the risk seems great.”

The first dictionary definition of “leader” describes a primary shoot of a plant, the main artery through which the organism lives and thrives. In much the same way, organizations prosper or die as the result of their leader’s ability to embody and communicate the organization’s vision. How the M&R leader influences others very much dictates the health of the M&R department and, ultimately, the entire organization.

Effective visions, according to Tom Peters, are inspiring. They should be “clear and challenging — and about excellence.” It consists of a concise statement or picture of where the organization and its people are heading and why they should be proud of it. An effective vision empowers people and prepares for the future while also having roots in the past.

Role of a Change Agent

The change agent is another important person who helps implement changes successfully. Change agents have the clout, conviction, charisma, and resourcefulness to make things happen and keep others engaged in implementing best practices. They usually have a number of skills including:

- They understand the organization’s politics to get work accomplished, but do not participate in the work.
- They have a good understanding of processes, the improvements needed, and interface issues, including any financial impact of the change.
- They are keen analyzers who can persuade and defend changes to every level of the organization
- They speak several organizational languages or traits — marketing, finance, operations, engineering, etc.
- They have a passion for improvement; in essence, they bring order out of chaos.

2.2 Leadership and Organizational Culture

What Is Organizational Culture?

Culture refers to an organization's values, beliefs, and behaviors. In general, it is the beliefs and values which define how people interpret experiences and behave, individually and in groups. Culture is both a cause and a consequence of the way people behave. Cultural statements become operationalized when leaders articulate and publish the values of their organization. They provide the pattern for how employees should behave. Organizations with strong work cultures including reliability cultures achieve higher results because employees sustain focus both on ***what*** to do and ***how*** to do it.

Behavior and success are two key enablers in creating the culture. There is circular flow of mutual causation among organizational behavior, success, and culture, as shown in Figure 2.2. When a change is accepted by the team members, it changes their behavior. They do tasks differently as required by the new change. Then, if their work gets more done easily, they can see some success. This success makes them accept the change and leads to changing habits or routine work methods. Eventually it becomes part of culture to do the tasks the new way (Figure 2.3).

Changing a culture from reactive thinking to proactive follows a similar process. It has to be shown why preventive and condition based approaches are better than reactive work. Making people change what

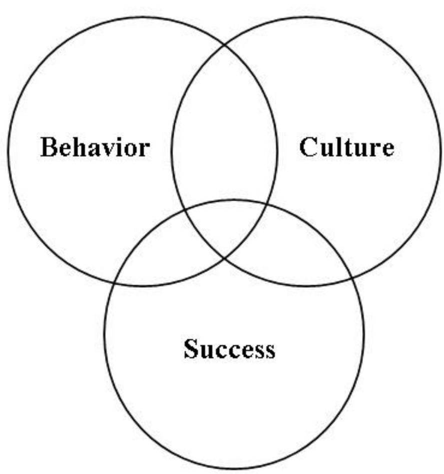


Figure 2.2 Organizational Culture and Success Flow.

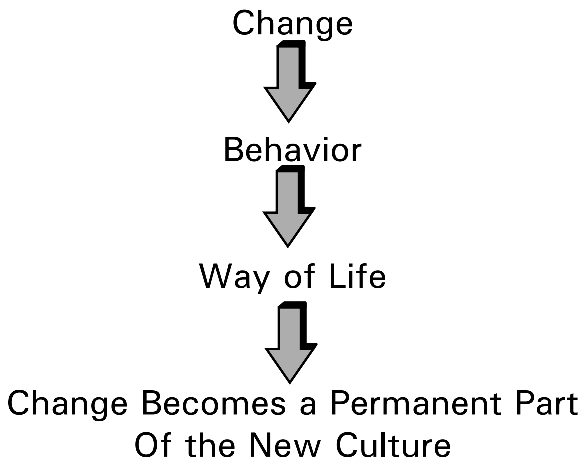
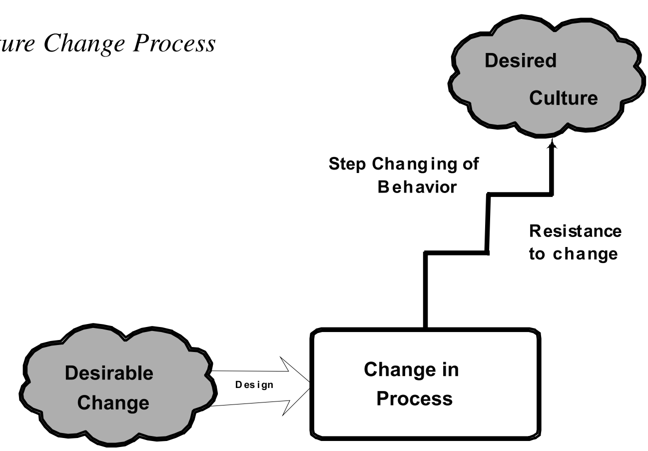


Figure 2.3 The Role of Change

they do or how they think takes time. After all, it took them long time to build their habit to begin with. People do certain things in particular ways. In turn, when we ask them to do differently or ask them to buy into our plan (vision), we are taking them out of their comfort zone. We must have very convincing reasons for people to change; we must inspire them to accept change. These reasons would help greatly the in implementation process. We have found that implementing changes in small steps or in a small pilot area helps the process. Figure 2.4 shows the culture change process.

Figure 2.4 Culture Change Process



Two key elements of any successful effort to change the culture are:

1. Influencing the behavior to change
2. Overcoming resistance to change

To influence the behavior to change, the following actions are suggested:

- Increase understanding (i.e., why the change is needed and how it relates to vision)
- Goal setting and expectations
- Praise, rewards, and celebration
- Roles definition and clarification
- Procedures and standards
- Persistence, tenacity, and discipline

To overcome resistance to change, the following actions are suggested:

- Listen and communicate
- Create awareness
- Educate and train to create understanding
- Get team members involved and let them see some success
- Empower team members to improve, tailor the process — change if needed

Leaders at both the corporate and plant levels must keenly understand the impact reliability has on the bottom-line performance of the organization. The valuation of an asset-dependent organization is significantly affected by the effectiveness with which that asset is managed.

2.3 Strategic Framework: Vision, Mission, and Goals

Both the organization and its people need to establish a strategic framework for significant success. This framework, which is illustrated in Figure 2.5, consists of:

- A vision for the future — Where are we and the organization going?
- A mission that defines what we are planning to do — What will be accomplished?
- Values that shape our actions — Why are we going in this direction?

Figure 2.5 A Strategic Framework for Success

- Strategies that zero in on key success approaches — How will we get there?
- Goals and action plans to guide our daily, weekly, and monthly actions — When will we get there?

An organization's success and our personal success depend on how well we define and live by each of these important concepts. In fact, it has been found that organizations whose employees understand the mission and goals enjoy a 29 percent greater return than other organizations, as reported by the Watson Wyatt Work Study.

The "Workplace 2000" Employee Insight Survey reported that U.S. workers want their work to make a difference, but 75% do not think their company's mission statement has become the way they do business.

Vision

A vision statement is a short, succinct, and inspiring declaration of what the organization intends to become or to achieve at some point in the future (Figure 2.6). Vision refers to the category of intentions that are broad, all-inclusive, and forward-thinking. It is the image that a business must have of its goals before it sets out to reach them. It describes aspirations for the future, without specifying the means that will be used to achieve those desired ends.

Corporate success depends on the vision articulated by the organizational leaders and management. For a vision to have any impact on the employees of an organization, it has to be conveyed in a dramatic and enduring way. The most effective visions are those that inspire, ask employees for their best and communicate that constantly. A vision statement is a pronouncement about what an organization wants to become. It should resonate with all members of the organization and help them feel proud, excited, and part of something much bigger than themselves. A vision statement should stretch the organization's capabilities and image of itself. It gives shape and direction to the organization's future. Visions range in length from a couple of words to several pages.

Warren Bennis, a noted writer on leadership, says, "To choose a direction, leaders must have developed a mental image of the possible and desirable future state of the organization. This image, which we call a vision, may be as vague as a dream or as precise as a goal or a mission statement".

The SMRP is a leading, not-for-profit, Maintenance and Reliability Society which provides opportunities for its members to exchange best practices and other educational and networking opportunities through conferences or workshops. It has taken the initiative to

Organization	Vision Statement
The Coca Cola Company	"Bringing to the world a portfolio of beverage brands that anticipate and satisfy peoples' desires and needs. Also, being a great place to work where people are inspired to be best they can be."
The Ford Motor Company	" To become the world's leading consumer company for automotive products and services."
Wal-Mart	"To give ordinary folk the chance to buy the same things as rich people."
Federal Express	"FedEx is committed to our People – Service – Profit Philosophy. We will produce outstanding financial returns by providing totally reliable, competitively superior, global, air-ground transportation of high quality goods and documents that require rapid, time-certain delivery."
Harley-Davidson	"To fulfill dreams through the experiences of motorcycling."
The Society for Maintenance & Reliability Professional's (SMRP)	" To become the global organization known for providing competitive advantage through improved physical asset management."

Figure 2.6

standardize maintenance definitions including metrics. The certification arm of SMRP has a vision to have at least one Certified Maintenance & Reliability Professional (CMRP) in every plant in the world.

Sometimes a picture portraying the vision can convey the message very effectively. Figure 2.7 is a picture displaying the intent of an organization's vision statement. This organization developed its vision picture in the mid-1990s to become the best M&R organization. The buses (people) are lined-up to see their successful M&R program. They have come a long way from a reactive mode to a proactive, reliability-based culture; their journey to excellence continues in spite of several changes in upper management of the M&R organization.

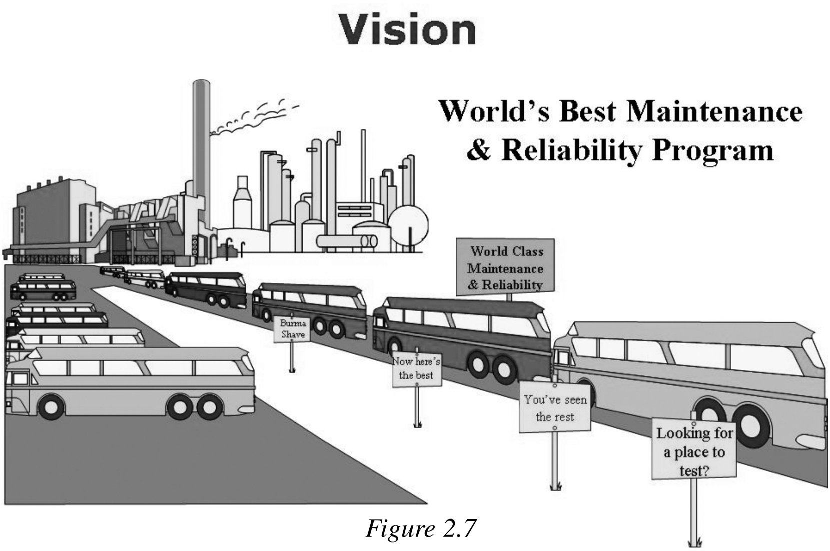


Figure 2.7

Examples of some maintenance vision statements include:

1. Maintenance Vision statement

To leverage a highly-skilled work force and employ effective maintenance strategies in order to position XYZ organization as the leading manufacturer across the industry.

2. Maintenance Vision statement

A world-class maintenance system with a standardized approach to plan, execute, track, and analyze maintenance and production processes.

The vision must convey the essence of how the organization desires to accomplish feats that prove to be big, exciting and compelling.

Mission Statements

Mission and vision statements are very different. A mission statement is an organization's vision translated into written form. It's the leader's view of the direction and purpose of the organization. For many corporate leaders, it is a vital element in any attempt to motivate employees and to give them a sense of priorities.

A mission statement should be a short and concise statement of goals and priorities. In turn, goals are specific objectives that relate to specific time periods and are stated in terms of facts. The primary goal of any business is to increase stakeholder value. The most important stakeholders are shareholders who own the business, employees who work for the business, and clients or customers who purchase products or services from the business.

The mission should answer four questions:

1. What do we do? What is the purpose of the organization?
2. How do we do it? What's unique about the organization?
3. For whom do we do it? Who are our customers and stakeholders?
4. What are our values and beliefs?

What do we do? This question should not be answered in terms of what is physically delivered to customers, but instead by the real and psychological needs that are fulfilled when customers buy our products or services. Customers make purchase decisions for many reasons, including economical, logistical, and emotional factors.

How do we do it? This question captures the more technical elements of the business. Our answer should encompass the physical product or service, how it is sold and delivered to customers, and how it fits with the need that the customer fulfills with its purchase.

For whom do we do it? The answer to this question is also vital as it will help us to focus our efforts. Anybody who uses our products or services is our customer. It could be a person or system next in the production line who takes what we build or provides a service. In a broader sense, it could include stakeholders for whom we ultimately do it.

What are our values and beliefs? Values and beliefs guide our plans, decisions, and actions. Values become real when we demonstrate them in the way we act and the way we insist that others behave. In forward-looking and energized organizations, values are the real boss. They drive and keep the workforce moving in the right direction.

Three Main Benefits Attributed to Mission Statements

1. They help companies focus their strategy by defining some boundaries within which to operate.
2. They define the dimensions along which an organization's performance is measured and judged.
3. They suggest standards for individual ethical behavior.

In his book, *First Things First*, Steven Covey points out that mission statements are often not taken seriously in organizations because they are developed by top executives, with no buy-in at the lower levels. But it's a pretty safe assumption that there probably is buy-in when we develop our own mission statements.

First Things First is actually about time management, but Covey and his co-authors use the personal mission statement as an important principle. The idea is that if we live by a statement of what's really important to us, we can make better time-management decisions. The authors ask, "Why worry about saving minutes when we might be wasting years?"

A mission statement may be valuable, but how in the world do we go about crafting one? As one way to develop a mission statement, Covey talks about visualizing your 80th birthday or 50th wedding anniversary and imagining what all our friends and family would say about you. A somewhat more morbid, but effective approach is writing your own obituary.

Can we visualize what it would be like if there were no asset failures or if production met their schedule without any overtime for one month, even three months, or if there was not a single midnight call for three months and we were able to sleep without worrying?

Developing a Mission Statement

1. The mission statement should describe the overall purpose of the organization.
2. If the organization elects to develop a vision statement before

developing the mission statement, ask "Why does the image, the vision exist — what is its purpose?" This purpose is often the same as the mission.

3. When wording the mission statement, consider the organization's products, services, markets, values, and concern for public image, and maybe priorities of activities for survival.
4. Ensure that wording of the mission is such that management and employees can infer some order of priorities in how products and services are delivered.

Some examples of mission statement related to M&R are:

A Physical Plant Mission Statement

The Physical Plant Department is a service organization whose main purpose and goal is to provide the best possible facilities and climate in which to support the instruction, learning programs, and public services of the university. We strive to make our customers feel nurtured, inspired, and uplifted by the excellence of our service and the caring concern of our service providers.

Mission Statement of a Maintenance Department

To manage the business of maintenance in a manner that facilitates a production effort which yields high quality products, low operating costs, utilizes all resources, and involves production and maintenance employees working together towards a common goal.

Mission Statement of a Maintenance Organization

To maximize equipment performance, fostering an environment of ownership and pride, through a structured approach to predictive and preventative maintenance.

Society of Maintenance & Reliability Professionals (SMRP's) Mission Statement

- Facilitate information exchange through a structured network of maintenance and reliability professionals
- Support maintenance and reliability as an integral part of business management
- Present a collective voice on maintenance and reliability issues and advance innovative maintenance and reliability practices

- Promote and support maintenance and reliability education for people, production, and quality processes to improve the work environment

If the environment changes, mission statements may require changing to include additional or different needs being fulfilled, delivery systems, or customer groups. With this in mind, vision and mission should be revisited periodically to determine whether modifications are desirable.

Corporate Strategy

Strategy is a very broad term which commonly describes any thinking that looks at the bigger picture. Successful organizations are those that focus their efforts strategically. To meet and exceed customer satisfaction, the business team needs to follow an overall organizational strategy. A successful strategy adds value for the targeted customers over the long run by consistently meeting their needs better than the competition does.

Strategy is the way in which an organization orients itself towards the market in which it operates and towards the other companies in the marketplace against which it competes. It is a plan based on the mission an organization formulates to gain a sustainable advantage over the competition.

The objectives must be:

- Focused on a result, not an activity
- Consistent
- Specific
- Measurable
- Related to time
- Attainable

Setting Goals

The major outcome of strategic planning, after gathering all necessary information, is the setting of goals for the organization based on its vision and mission statement. A goal is a long-range aim for a specific period. It must be specific and realistic. Long-range goals set through strategic planning are translated into activities that will ensure reaching the goal through operational planning. Examples of an M&R goal include achieving 90% PM compliance or reducing the overtime to less than 5%.

2.4 Reliability Culture

What is Reliability Culture?

Can we define reliability culture? What does it mean if someone says that organization XYZ has a reliability culture? Is there a metric to measure it? The problem is that culture — any kind of culture — is a "touchy-feely" concept that is difficult to define and specifically measure.

We can see the impact of a reliability culture in the final outcome or services provided by the organization. Reliability improves the bottom line of an organization because it can meet the customer's needs on time and cost effectively. In this organization:

- Assets are reliable and available as and when needed — High UPTIME
- Assets are functioning and producing as designed
- Maintenance costs are reasonable (at optimum level)
- Plant operates safely and reliably

The importance of reliability and implementing best M&R practices are discussed at the highest level of the organization. Most organizations talk about RCM/Reliability, but it's treated as the "program of the month" and loses its emphasis over time. Changing an existing culture of "run-to-failure" or little/no PM program to a sustainable reliability culture takes many years and consistent management support and resources.

In a reliability culture, *prevention* of failures becomes an emphasis at every level of organization. The entire work force is focused on asset reliability. The work force — operators, maintainers, engineers— think and act to ensure:

- Assets are available to produce when needed
- Assets are maintained at reasonable cost
  - Optimized PM plan (RCM/CBM based)
  - An effective facility maintenance plan — 80/20 principal applied to prioritize the work. Most of the work is planned and scheduled.

If an asset fails, it gets fixed quickly, the root cause is determined, and action is taken to prevent future failures. Facility/asset reliability analysis is performed on a regular basis to increase uptime. The work force is trained and taught to practice reliability-based concepts and best practices on a continuing basis.

Reliability Culture — Creating and Sustaining

Let us look into a real plant scenario where an asset breakdown/failure has occurred.

Operations reported that "Valve P-139" would not close. An Operations workaround was used to divert the process temporarily. The breakdown was reported to the Maintenance Department with an urgent request in the CMMS/EAM system to fix the valve.

The following events happened:

- Maintenance dispatched a mechanic to evaluate and fix the valve.
- Mechanic noticed "a burning smell" upon arrival, and suspected the electric motor on a hydraulic pump had burned up. He called an electrician to help.
- Electrician determined that the motor had failed. He asked his supervisor to find a replacement motor.
    - Supervisor called the Storekeeper, who found that no spare motor was available.
- Supervisor called Operations to report that motor failed and would take a couple of days to repair. Operations demanded the repair immediately, so the supervisor called the Plant Engineer to help locate a spare motor.
- Plant Engineer and Supervisor found the same type of motor on a similar system not being used. Supervisor sent another crew to remove this motor while the first crew removed the failed motor.
- Maintenance replaced the motor and adjusted linkages due to sluggish operation. The valve was released to operation.
    - The work order was closed with comment "valve was fixed."
    - Operation was so happy with a four-hour repair time (rather than two days) that they sent an e-mail thanking the maintenance crew for a *job well done*.

What kind of culture does this plant have? What kind of message is being delivered to the workforce? It appears that this organization has a reactive culture. Fixing things are recognized and appreciated.

Now, let us look into another plant with the same breakdown scenario, but where the sequence of events happened a little differently:

- Maintenance Supervisor/Scheduler visited the site and assessed the failure, finding that the valve linkage was tight and dry, along with a failed electric motor on a hydraulic system.
- Supervisor/Scheduler assigned a mechanic and an electrician, and requested both a 6-month chronological history report and a recommended parts list. He also alerted the plant engineer of the problem.
- Electrician determined that the motor had failed (burned). The overload relays didn't function properly. Mechanic found that linkage was tight due to inadequate lubrication.
- The repair history (attached to the Work Order) showed the following problem — a few months ago:
    - Problem with valve closing. Mechanic had adjusted and greased the linkage. The hydraulic pressure on the system had been raised from 1500 psi to 1800 psi to make the actuator and linkage work smoothly.
- Repair plan included replacement of the motor and overload relays, restoration of hydraulic pressure to system design, and greasing/ adjustment of linkage. A spare motor was available as a part of the repairable program.
- Work was completed as planned. Operator was supporting the repair and helped in testing the system. The valve returned to operation.
    - The WO was closed and *repair details documented.*
- Operations were pleased with a two-hour repair. The maintenance manager personally thanked the maintenance crew for a job well done and for finding the root cause. He then asked them for a *plan of further action needed to improve the reliability* for review in 10 days.

Now let us review what happened in this plant. Is the CMMS/EAM system providing the data we need to make the right decisions? What kind of message is being delivered to the workforce? What kind of culture is in this plant?

In this plant, the CMMS/EAM system has provided the information to help make the right decisions. The maintenance manager is emphasizing failure prevention. It's a proactive culture — a step in the right direction

Now let us look into another plant, a similar type of situation, but where events happened a little differently. In this case, the plant operations (Operator) noted that on Valve # P-139

- Motor: Current data on operator's panel indicate a higher current. The visual inspection and site visit indicated that valve actuator running sluggish. Maintenance was alerted by the operator.
- Maintenance evaluated the situation with the help of the operator and planned the repair on a schedule.
    - The repair was completed and there was no unscheduled down time. All repairs were documented in the CMMS/EAM sys tem for asset history.
    - PM tasks were reviewed and root cause analysis performed. Based on this analysis, PM tasks were updated. A work order to redesign linkage based on root cause analysis was also issued to design / engineering.
    - Operators were thanked for watching the asset/system closely

What happened in this plant? What kind of culture does this organization has? In this plant, "Failure" was caught before it happened and

- Operations and Maintenance worked together as a team
- System provided the "warning" data
- Process was designed to make it happen

In this organization, the reliability/maintenance leaders have done their work. They provided the right tools, trained both operators and maintenance, and created the right culture.

2.5 Summary

Corporate success depends on the vision articulated by the organizational leaders and the management. For a vision to impact the employees of an organization, it has to be conveyed in a dramatic and enduring way. The most effective visions are those that inspire, usually asking employees for the best, the most, or the greatest. A vision explains where the organization wants to be and is an important element of creating a reliability culture.

Culture refers to an organization's values, beliefs, and behaviors. In general, it is concerned with beliefs and values on the basis of which people interpret experiences and behave, individually and in groups. Cultural statements become operationalized when leaders articulate and publish the values of their organization which provide patterns for how employees should behave. Organizations with strong reliability cultures achieve higher results because employees sustain focus both on ***what*** to do and ***how*** to do it.

When we visualize, we are able to materialize; to convert our vision into goals and then into reality. Leadership is an enabler in this process by providing direction and resources to make this happen.

Creating a sustainable reliability culture is a long journey. Many organizations get impatient and stop supporting reliability change or implementing best practices in the organization; they fail to understand it takes many years to create a sustainable reliability culture.

To sustain a reliability culture, the reliability/maintenance leaders in an organization must continue to provide the right tools, training, and education to both the operators and maintenance together as a team. They need to ensure that the work force is always current on:

- Knowledge — of best practices
- Teamwork — to assure communication and understanding
- Focus — on the right goals for business success
- Planning — to create a roadmap for knowing where they are and where they want to be
- Processes — documentation, adherence, and discipline

- Measurements — to provide feedback and control and to ensure that they, the leadership, continue to support the continuous improvement environment and are creating a conducive sustainable culture

2.6 Reference and Suggested Reading

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Chapter 3

Understanding Maintenance

"Your system is perfectly designed to give you the results that you get."
-- W. Edwards Deming

After reading this chapter, you will be able to understand:

- Why do maintenance?
- Key maintenance terms
- The objective of maintenance
- Maintenance tasks
- Maintenance quality issues
- Maintenance benchmark data

3.1 Introduction

What Is Maintenance and Why Is it Important?

Maintenance is concerned with keeping an asset in good working condition so that the asset may be used to its full productive capacity. The maintenance function includes both upkeep and repairs. The dictionary defines maintenance as "the work of keeping something in proper condition; upkeep." A broader definition is:

Keep in 'designed' or an acceptable condition; Keep from losing partial or full functional capabilities; Preserve, protect

This definition implies that the term *maintenance* includes tasks performed to prevent failures and tasks performed to restore the asset to its original condition.

However, the new paradigm of maintenance is related to *capacity assurance*. With proper maintenance, the capacity of an asset can be realized at the designed level. For example, the designed capacity of a production equipment of 10 units per hour could be realized only if the equipment is operated without considerable downtime for repairs.

An acceptable capacity level is a target capacity level set by management. This level cannot be any more than the designed capacity. Consider production equipment that is designed to make 500 units per hour at a maintenance cost of $150 per hour. If the equipment is down 10% of the time at this level of maintenance, the production level will be reduced to 450 units per hour. However, if the maintenance department, working with the production department together as a team, can find a way to reduce the down time from 10% to 5% at a slightly increased maintenance cost/hour, this reduction will increase the output by another 25 units/hour. Therefore, it is conceivable that the management would be able to justify the increased maintenance cost. Thus capacity could be increased closer to designed capacity by reducing downtime.

Unfortunately, the literature related to maintenance practices over the past few decades indicates that most companies did not commit the necessary resources to maintain assets in proper working order. Rather, assets were let to fail; then whatever resources needed were committed to repair or replace the failed asset or components. In fact, maintenance function was viewed as the necessary evil and did not receive the attention it deserved.

However, in the last few years, this practice has changed dramatically. The corporate world has begun recognizing the reality that maintenance does add value. It is very encouraging to see that maintenance is moving from so-called "backroom" operations to corporate board room. A case in point —in the 2006 annual report to investment brokers on the Wall Street, the CEO of Eastman Chemical included a couple of slides in his presentation related to maintenance and reliability stressing the company's strategy of increasing equipment availability by committing adequate resources for maintenance.

In this chapter, we will be discussing the role maintenance plays in an organization and why it's important, including key elements.

Key Maintenance Terms and Definitions

Asset

The physical resources of an organization, such as equipment, machines, mobile fleet, systems, or their parts and components, including software that performs a specific function or provide a service; sometimes referred to as physical assets.

Component

A configured item within the hierarchy of an asset for which there is a maintenance management need to track cost, installed location, service history, manufacturer model/serial number, warranty, and purchase/inventory data. This item may be either a permanent or temporary part of an asset. A temporary item is part dismantled from asset to asset depending upon the requirements of operations and maintenance. Examples of components include: electric motors, valves, gearboxes, pumps, and switch gears.

Failure Mode and Effects Analysis (FMEA)

A technique to examine an asset, process, or design to determine potential ways it can fail and the potential effects; and subsequently identify appropriate mitigation tasks for highest priority risks.

Maintenance, Backlog

Maintenance tasks that are essential to repair or prevent equipment failures that have not been completed yet.

Maintenance, Capital Project (CPM)

Major repairs, e.g., overhauls and turnaround projects, valued over a certain threshold are sometime treated as capital projects for tax purposes. If these projects are essential to restoring the asset back to the designed capacity — not to add additional capabilities — they should be treated as maintenance costs.

Maintenance, Condition Based (CBM)

Maintenance tasks that are required based on the health of an asset as determined from non-invasive measurements of operation used for monitoring equipment conditions. CBM allows preventive and corrective actions to be optimized by avoiding traditional calendar or run-time directed maintenance.

Maintenance, Corrective (CM)

Repair actions initiated as a result of observed or measured conditions of an asset after or before the functional failure.

Maintenance, Predictive (PdM)

PdM is an equipment maintenance strategy based on measuring the condition of equipment in order to assess whether it will fail during some future period, and then taking appropriate action to avoid the consequences of that failure. The condition of equipment could be measured using condition monitoring, statistical process control, or equipment performance, or through the use of the human senses. The terms Condition Based Maintenance (CBM), On-Condition Maintenance, and Predictive Maintenance are used interchangeably.

Maintenance, Preventive (PM)

PM is an equipment maintenance strategy based on inspection, component replacement, and overhauling at a fixed interval, regardless of its condition at the time. Usually scheduled inspections are performed to assess the condition of assets. Replacing service items (e.g., filters), adding or changing oils and belts, and lubricating parts are a few examples of PM tasks. PM inspection may require another work order to be written to repair other discrepancies found during the PM.

Maintenance, Reactive (RM)

Activity carried out to fix an asset in response to failure or breakdown. When it is performed in emergency mode, it may cost 3–5 times more.

Maintenance, Operator Based (OBM)

OBM involves operators performing some basic maintenance activities. Operator-based maintenance is a cost effective practice to perform minor routine, and recurring maintenance tasks by the operators to keep the asset working efficiently for its intended purpose.

Maintenance, Run-to-Failure (RTF)

A management strategy (policy) that permits a specific failure mode to occur without any attempts to prevent it. A deliberate decision based on economical effectiveness.

Proactive Maintenance Work

This is a complete list of all maintenance tasks that are completed to avoid failures or to identify defects that could lead to imminent failures. Usually the list includes routine preventive and condition/predictive maintenance tasks that are carried out in a planned and scheduled manner.

Reliability

The probability that an asset or item will perform its intended functions for a specific period of time under stated conditions.

Reliability Centered Maintenance (RCM)

A systematic, disciplined process for establishing the appropriate maintenance strategies for an asset/system in its operating context, to ensure safety, mission compliance, and system function. The process defines system boundaries and identifies functions, functional failures, and likely failure modes. It develops a logical identification of the causes and effects (consequences) of system and functional failures to arrive at an efficient and effective asset management strategy for reducing the probability of failure.

3.2 Maintenance Work Tasks

Maintenance Tasks to Prevent and Repair Failures

An asset has a predefined life expectancy based upon how it has been designed. The design life of most assets requires periodic maintenance. For example, belts and chains require adjustment, alignment of shafts such as pump-motor shafts need to be properly maintained, filters need to be changed at regular intervals, proper lubrication on rotating machinery is required, and so on. In some cases, certain components need replacement after a specified number of hours of operations, e.g., a pump bearing on a hydraulic system to ensure that the system lasts through its design life. Anytime we fail to perform maintenance activities, we may be shortening the operating life of the asset. Over the past 40 years, many cost-effective approaches have been developed to insure an asset reaches or exceeds its design life. Instead of waiting for assets to fail and then fix them, maintenance actions are performed to keep assets in good working condition to provide continuous service. Two major categories of maintenance actions are:

- Preventive maintenance tasks performed to discover deficiencies or imminent failures and to provide servicing that keeps an asset working.
- Corrective maintenance, sometimes called "repair," is conducted to correct the deficiencies and to make the asset work again after it has failed or stopped working.

When an asset breaks down, it fails to perform its intended function and disrupts scheduled operation. This functional loss — partial or total — may result in defective parts, speed reduction, reduced output, and unsafe conditions. For example, a wear or slight damage on a pump impeller, which reduces output, is a function reduction failure. Function-disruption or reduction failures that are not given due attention will soon develop into asset stoppage if not acted on.

Many abnormalities such as cracks, deformations, slacks, leakages, corrosions, erosions, scratches, excessive heats, noises, and vibrations are the indicators of imminent troubles. Sometimes these abnormalities are neglected because of the insignificance or the perception that such abnormalities will not contribute to any major breakdowns. The tendency to overlook such minor abnormalities soon may grow and contribute to serious catastrophic failures. It is not uncommon to receive queries from production staff in response to a "high temperature or vibration condition" about how long we can continue running.

It has been observed that a high percentage of the failures occur during startups and shutdowns. However, asset failure could also be due to poor maintenance. Causes that go unnoticed are termed as "hidden abnormalities." The key to achieving zero failures is to uncover and rectify these hidden abnormalities before failure actually occurs. This is the fundamental concept of maintenance, specifically Preventive, Condition/Predictive Maintenance, and Operator-based or supported maintenance, also known as Total Productive Maintenance (TPM). These and others practices will be discussed in more details later in this and other chapters.

Preventive Maintenance (PM) requires that maintenance or production personnel pay regular visits to monitor the condition of an asset in a facility. The basic objective of PM visits is to take a look at the asset to determine if there are any telltale signs of failure or imminent failure. Also, depending on the type of the asset, a checklist or a procedure with task details indicating what to check or what data to take may be used, e.g., change filter, adjust drive belts, and take bearing clearance data or oil samples. The observers also document the abnormalities and other findings. These abnormalities need to be corrected before they turn into failures. If an asset fails, it needs to be repaired. Correcting these abnormalities is called corrective maintenance.

Maintenance Work Task Classifications:

Maintenance work tasks can be classified in two major categories:

Preventive Maintenance (PM)

- Time (Calendar)-based maintenance (TBM) (Age Related)
- Run-based maintenance (RBM) (Usage Related)
- Condition-based maintenance (CBM) (Health Related) (aka Predictive)
- Operator-based maintenance (OBM) (Operations related) (aka Autonomous Maintenance, a pillar of TPM)

Corrective Maintenance (CM)

- CM Routine work resulted from PMs: Planned & Scheduled
- CM Major Repairs/Projects: Planned & Scheduled
- CM Reactive: Unplanned/Unscheduled (aka Breakdown/Emergency)

Some maintenance professionals classify maintenance in the following categories: PM, CBM/PdM, Proactive Work resulting from PM and CBM/PdM, and CM – Reactive (Breakdowns / Emergency). It really does not matter how we classify them as long as maintenance management systems can provide us data in the format to help us to make the right decisions. Our objective is to reduce reactive breakdowns and then adjust or increase PM and CBM work accordingly.

Preventive Maintenance (PM)

Preventive maintenance refers to a series of actions that are performed on an asset on schedule. That schedule may be either time-based or based upon machine-run time or the number of machine cycles. These actions are designed to detect, preclude, or mitigate degradation of a system and its components. The goal of a preventive maintenance approach is to minimize system and component degradation and thus sustain or extend the useful life of the asset.

Preventive maintenance is the planned maintenance of assets designed to improve asset life and avoid unscheduled maintenance activity. PM includes cleaning, adjusting, and lubricating, as well as minor component replacement, to extend the life of assets and facilities. Its purpose is to minimize failures. Neither assets nor facilities should be allowed to go to the breaking point unless we have selected a run-to-failure strategy for that specific asset. In its simplest form, preventive maintenance can be compared to the service schedule for an automobile. The amount of preventive maintenance needed at a facility varies greatly. It can range from walk-through inspections of assets and facilities to measuring bearing clearances, checking pump and motor alignment, taking Infrared (IR) pictures of electrical systems, etc., while noting other deficiencies for later corrections.

The objective of preventive maintenance can be summarized as follows:

- Maintain assets and facilities in satisfactory operating condition by providing for systematic inspection, detection, and correction of incipient failures either before they occur or before they develop into major failure.
- Maintenance, including tests, measurements, adjustments, and parts replacement, performed specifically to prevent failure from occurring.
- Record asset health condition for analysis which leads to the development of corrective tasks.

Preventive maintenance is typically performed based on the calendar time. Maintenance personnel schedule periodical visits to an asset based on fixed time intervals, for example every three or six months. Although better than no PM at all, time-based PMs are not the optimal way to run PM programs. They may result in too much time being spent on an asset. Numerous visits to assets with "no data – abnormalities found" can be regarded as wasted maintenance dollars. If this happens, the

PM periodicity should be reevaluated and adjusted. Nevertheless, time-based PMs are a good approach for assets having fixed operating schedule such as 24/7 or 80 hours/week operation.

Typically, the next step up from time-based PMs is performing PMs based on asset cycles or run time. Intuitively, this approach makes sense. An asset does not have to be checked repeatedly if it has not been used. Generally speaking, it is the actual operation of the asset that wears it down, so it makes sense to check the asset after it has been working for a specified amount of time to cause some wear. It may be necessary either to adjust or replace the component.

Condition Based Maintenance (CBM)

Condition Based Maintenance (CBM), also known as Predictive Maintenance (PdM), attempts to evaluate the condition of an asset by performing periodic or continuous asset monitoring. This approach is the next level up from runtime-based maintenance. The ultimate goal of CBM is to perform maintenance at a scheduled point in time when the maintenance activity is most cost effective and before the asset fails in service. The "predictive" component stems from the goal of predicting the future trend of the asset's condition. This approach uses principles of statistical process control and trend analysis to determine at what point in the future maintenance activities will be appropriate and cost effective.

CBM inspections mostly are performed while the asset is in service, thereby minimizing disruption of normal system operations. Adoption of CBM/PdM in the maintenance of an asset can result in substantial cost savings and higher system reliability.

CBM / PdM technologies used to evaluate assets condition include:

- Vibration analysis
- Shock Pulse Method (SPM)
- Oil analysis
- Infrared (IR) thermography
- Partial discharge & Corona detection
- Acoustic / Ultrasonic — sound level measurements
- Electrical — amperage plus other data
- Operational performance data — pressure, temperature, flow rates, etc.

Vibration analysis is very effective on rotating assets, but can be the most expensive part of a PdM program to set up and make operational.

Oil analysis is another program that, where relevant, eventually can be more predictive than any of the other technologies. Acoustical analysis can be done at a sonic or ultrasonic level.

Sonic technology is useful mostly on mechanical assets whereas ultrasonic technology can detect electrical problems and is more flexible and reliable in detecting problems. Details of these technologies will be discussed in Chapter 8.

Basically, in the CBM approach, the maintenance need is based on the actual condition of the machine rather than on some preset schedule. Activities such as changing oil are based on time, like calendar time or asset run time. For example, most of us change the oil in our cars every 3,000–5,000 miles driven. This is effectively basing the oil change needs on asset run time. No concern is given to the actual condition and performance capability of the oil. It is changed because it is time. This methodology would be analogous to a preventive maintenance task.

On the other hand, if we ignore the vehicle run time and have the oil analyzed at some regular period to determine its actual condition and lubrication properties, then we may be able to extend the oil change until the car has been driven 10,000 miles, or more.

This is the advantage of utilizing condition based maintenance. CBM is used to define needed maintenance tasks based on quantified asset conditions or performance data. The advantages of CBM are many. A well-established CBM program will cost effectively eliminate or reduce asset failures. It will also help to schedule maintenance activities to minimize overtime cost. In addition, we will be able to minimize inventory and order parts, as required, well ahead of time to support the downstream maintenance needs.

Past studies have shown that a well-implemented CBM program can provide an average savings of 10% (7–15%) over a program utilizing preventive maintenance alone. These savings could easily exceed 30–40% if there is not a good PM program in place. In fact, independent surveys and technical papers presented at the International Maintenance Conferences 1999–2002 and author's own experience indicate the following industrial average savings resulting from a good established condition based maintenance program:

- Reduction in maintenance costs: 15–30%
- Reduction in downtime: 20–40%
- Increase in production: 15–25%

On the down side, starting a CBM program is not cheap. Testing equipment may cost in excess of $40,000. In addition, training plant personnel to utilize PdM technologies effectively will require considerable funding. Program development will require an understanding of predictive maintenance and a firm commitment to make the program work by all facility organizations and management. How the CBM team should be organized is another issue. We have found that a centralized dedicated team is a good way to start a program. This approach helps in standardizing testing methods and practices.

The CBM approach consists of scheduling maintenance activities only when mechanical or operational conditions warrant — by periodically or continuously monitoring the machinery for excessive vibration, temperature, noise, etc. When the condition gets to a level that has been predetermined to be unacceptable, the asset is shut down. The asset is then repaired or has damaged components replaced in order to prevent more costly failures from occurring. This approach works very well if personnel have adequate knowledge, skills, and time to perform the CBM work. In addition, the company must allow asset repairs to be scheduled in an orderly manner. The approach provides some lead-time to purchase materials for the necessary repairs, reducing the need for a high parts inventory. Because maintenance work is only performed when it is needed, there is likely to be an increase in production capacity.

Advantages of CBM

Condition Based Maintenance can:

- Warn of most mechanical problems in time to minimize unexpected failure, the risk and consequences of collateral damage, and adverse impact on safety, operations, and the environment. It will reduce the number of preemptive corrective actions.
- Increase equipment utilization and life; minimize disruption to mission and schedule. It will decrease asset and process downtime, resulting in increased availability.
- Reduce maintenance costs — both parts and labor.
- Reduce a significant amount of calendar / run-based preventive maintenance.
- Minimize cost and hazard to asset that result from unnecessary overhauls, disassemblies, and PM inspections.
- Increase the likelihood that components operate to optimum lifetime.

In some cases, replacement prior to end-of-life is more efficient for meeting operational requirements and optimum cost.
- Reduce requirements for emergency spare parts.
- Increase awareness of asset condition.
- Provide vital information for continuous improvement, work, and logistic planning.
- Improve worker safety.
- Increase energy savings.

However, CBM cannot:
- Eliminate defects and problems, or stop assets from deteriorating.
- Eliminate all preventive maintenance (e.g., lubrication, leak inspections, and IR inspection of electrical systems).
- Reliably and effectively warn of fatigue failures.
- Reduce personnel or produce a major decrease in lifetime maintenance costs without a commitment to eliminating defects and chronic problems.

CBM is not a "silver bullet." Some potential failures, such as fatigue, or uniform wear on a blower fan are not easily detected with condition measurements. In other cases, sensors may not be able to survive in the environment; measurements to assess condition may be overly difficult and may require major asset modifications.

Why Have a PM Program

The most important reason to have a PM program is to ensure that assets don't fail prematurely, that they keep producing or providing service as intended. PM programs should improve production capacity and reduce overall maintenance costs by:
- Reducing production downtime — the result of fewer asset failures.
- Increasing life expectancy of assets, thereby eliminating prema ture replacement of machinery and asset.
- Reducing overtime costs and providing more economical use of maintenance personnel due to working on a scheduled basis instead of an unscheduled basis to repair failures.
- Reducing cost of repairs by reducing secondary failures. When parts fail in service, they usually damage other parts.
- Reducing product rejects, rework, and scrap due to better overall asset condition.
- Identifying assets with excessive maintenance costs, indicating

the need for corrective maintenance, operator training, or replacement of obsolete assets.

- Improving safety and quality conditions.

How to Have a Successful PM Program

Scheduling and execution are the keys to a successful PM program. PM programs should be automated by using Computerized Maintenance Management Systems (CMMS) or Enterprise Asset Management (EAM) systems. Priority should be given to preventive maintenance work. In addition, a monitoring process should be established to ensure a 90% or better schedule compliance and quality of work performed. The rule of thumb is that each hour of PM work should develop 1/2 – 2 hours of corrective maintenance type work and all of that work should be planned and scheduled.

In addition, to making the PM program a success, create a "living PM program" consisting of the following key elements:

- Continually review processes, procedures, and tasks for applicability, effectiveness, and interval frequency; these should be optimized as required. Get the right people both in operation and maintenance involved in the review process.
- Standardize procedures and maintain consistency on asset and components.
- Identify and execute mandated tasks to ensure regulatory compliance.
- Apply and integrate new predictive technologies where effective.
- Ensure task instructions cover lock out / tag-out procedures and all safety requirements.

Ensure operation and maintenance personnel understand the importance of PM practice and provide feedback for improving PM instructions and procedures.

The 10 Percent Rule of PM

A PM plan must be executed per schedule. The best practice is to use the 10 percent rule of PM — a time-based PM must be accomplished in 10 percent of the time frequency or it is out of compliance. Many organizations use a "PM compliance" metric as a measurement of their maintenance department's performance. If an asset is on a 30-day PM schedule, it should be executed within +/-3 days of its due date; otherwise it is out of compliance. This rule should apply to all PMs, but we must ensure that, at a minimum, *critical* assets are being maintained properly at the right time, within 10 percent of time frequency.

Organizations who have implemented the 10 percent rule, have been found to have increased reliability of the assets due to consistent and disciplined approach.

If we are performing Preventive Maintenance on an asset that continues to fail, we are in reactive maintenance mode. The PM plan should be reviewed and adjusted.

Number of Failures	0	1	2	3	4	5
Number of Months Failures Occurred	3	12	10	8	2	1

Figure 3.1 Failures in the Stamping Department

Example

The following example compares preventive maintenance with breakdown maintenance. Figure 3.1 summarizes the failures that a sheet metal press in a stamping department recorded over the last twelve months.

Currently this department doesn't have a formal PM program. Each failure costs on average $450, which comprises of $ 350 labor and $100 material costs.

The press manufacturer has proposed performing PM on all the presses at a cost of $300/month; they guarantee not more than one failure per month. Should we accept their proposal to establish this PM program? For the sake of simplicity, ignore production losses due to failures. We can use the expected value process to evaluate the PM proposal (Figure 3.2).

The PM proposal should be accepted as it will save a little over $112/month. Note that this potential saving doesn't include increased production resulting from reduced equipment downtime.

Operator Based Maintenance (OBM)

The operator is actually the most important member of the maintenance team. Well-informed, trained, and responsible operators will ensure that assets are being kept in good working order.

# of Failures (x)	Frequency f(x)	Frequency P(x)	Expected Value x * P (x)
0	3	0.083	0
1	12	0.333	0.333
2	10	0.278	0.556
3	8	0.222	0.667
4	2	0.056	0.222
5	1	0.028	0.139
Total	36	1	1.917

Average failures / month = 1.917

Average Number of failures/month	=1.917
Expected failure cost/month	=1.917 X $450 = $862.65
Proposed PM cost	=$300 + cost of repairing 1 failure
	=$300 + $450 = $750
Expected savings from PM program	=$862.65– $750 = $112.65 /month

Figure 3.2 Expected Value of Failures and PM Cost

Operators are the first line of defense against unplanned asset downtime. OBM assumes that the operators who are in daily contact with the assets can use their knowledge and skills to predict and prevent breakdowns and other losses.

The main objective of an Operator's Maintenance program (aka autonomous maintenance program) is to equip operators with the following asset-related skills:

1. Ability to detect abnormalities
2. Ability to correct minor abnormalities and restore function, if they can
3. Ability to set optimal asset conditions
4. Ability to maintain optimal equipment conditions

Autonomous maintenance is one of the basic pillars of Total Productive Maintenance (TPM). TPM is a Japanese maintenance philosophy which involves operators performing some basic maintenance activities. The operators learn the maintenance skills they need through a training program. They then perform the following tasks:

- Conduct general inspection.
- Keep assets clean and all areas accessible.
- Identify and eliminate problem sources.
- Support and create cleaning and lubricating standards and procedures.
- Standardize through visual workplace management.
- Implement autonomous asset management.
- Perform minor maintenance and service items, e.g., replacing filters, lubricating, and changing oil.
- Work with the maintenance team to repair what they are unable.

The operators use the following four sensory tools to identify problem areas, then either fix them or get help to get the problems repaired before they turn into major failures.

1. Look for any abnormalities — clean, in place, accessible
2. Listen for abnormal noises, vibrations, leaks
3. Feel for abnormal hot or cold surfaces
4. Smell abnormal burning or unusual smell

The TPM maintenance approach will be discussed in more details in Chapter 7.

Corrective Maintenance (CM)

CM, sometimes called repair, is performed to correct the deficiencies found during PM and CBM assessment; it restores the asset in good working condition after it has failed or stopped working. CM is an action initiated as a result of an asset's observed or measured condition before or after the functional failure. The CM work can be further classified into three categories:

CM — Scheduled

CM–Scheduled is a repair activity performed to mitigate potential asset failure or correct deficiencies found during PM and CBM tasks. It brings an asset to its designed capacity or to an acceptable level in a planned way. This work should be planned and scheduled.

CM — Major Repairs / Projects (Planned & scheduled)

In many organizations, all major repairs or improvement work valued over a certain threshold — e.g., overhauls and turnaround projects — are treated as capital projects for tax purposes. If these projects are to bring the asset back to the designed capacity, not to add additional capabilities, they should be treated as corrective maintenance. In that case, they should always be planned and scheduled.

CM — Reactive (Unscheduled) aka Breakdowns / Emergency

Corrective Maintenance — Reactive (Unscheduled) is basically repairing of the assets after they fail. This work is also known as breakdown or failure repair work. Most of the time, completing this work interferes with the regular weekly schedule. Unscheduled work costs much more than planned and scheduled work. Planning and scheduling process will be discussed in detail in Chapter 4.

Many surveys / studies reported at International Maintenance Conferences, Society for Maintenance & Reliability Professionals' annual Conferences, and at Reliabilityweb indicate that reactive maintenance is still the predominant mode of maintenance. These studies break down the average maintenance program as follows:

- 55% Reactive — (CM Unscheduled)
- 30% Preventive — Calendar and Run Time
- 15% CBM / PdM

Note that this survey indicates that 55% of maintenance resources and activities of an average facility are still reactive in nature.

This data is misleading, however, and does not tell the complete story. Most surveys ask "What is the percent of PM and CBM work in your organization?" Too often, this question assumes that the remaining work is reactive. This is probably not true because there is some corrective scheduled work too. Furthermore, this number is an average number which includes all types of organizations, including top quartile as well as bottom. Based on discussions with many M&R professionals, reviews of

Maintenance Work Type	Leaders Top Q	Laggards Bottom Q	In Between II and IIIQ	Best of Best (World Class)
PM — Calendar & Run	15 - 20%	10 - 15%	20 - 25%	<20%
PM — CBM/PdM	30 - 35%	0 - 5%	10 - 15%	>35%
PM — Planned and Scheduled	35 - 40%	15 - 20%	30 - 35%	>30%
PM — Unscheduled (Reactive)	10 - 15%	65 - 70%	30 - 35%	<10%

Figure 3.3 Maintenance Work Type Distribution by Leaders and Lagards

several surveys conducted by the professional societies or organizations, and our own experience, Table 3.3 shows a more accurate estimated distribution of maintenance work.

There is confusion when we try to mix maintenance work with how we respond to getting the work done. For example, is emergency work really CM – Unplanned/Unscheduled or is it reactive work that needs to be done now. In some organizations, the breakdown work is called urgent maintenance, but could be done within 48 hours. Some regular work, also sometimes called routine work, may need to be completed in 5 or 7 days. These examples are not the work type, but just how we respond to getting it done.

Sometime a decision is made to take no actions or make no efforts to maintain the asset as the original equipment manufacturer (OEM) originally intended. Therefore, no PM program is established for that particular asset. This maintenance strategy, called Run-to-Failure (RTF), should be applied only after a risk to the business has been analyzed and its cost effectiveness determined. In reality, this work should not be considered failure or reactive work because we made the decision in advance not to perform any PM or CBM based on economical justification.

Proactive Maintenance

Proactive Maintenance is another term used often. It is an aggregate of maintenance actions taken proactively to find incipient failures and then to reduce the maintenance repair needs. It includes all PM, CBM, and Operated-Supported / TPM actions, including work identified as a result of root and failure analysis. In some organizations, it is calculated as a ratio of (all maintenance work minus unscheduled corrective maintenance) divided by all maintenance work.

Proactive Maintenance is also a controversial term. In some M&R professionals' view, only activities in the PM and CBM arena should be called proactive. To some others, anything that's on the maintenance schedule is proactive — that is, any maintenance work that has been identified in advance and is planned and scheduled. This latter definition makes much better sense.

3.3 Other Maintenance Practices

It is said that "Accidents do not happen, they are caused. The same is true for asset failure. Assets fail due to basically two reasons: poor design and human error. Our negligence, ignorance, and attitude are the prime factors of human errors. Several studies have indicated that over 70 percent of failures are caused by human errors such as overloading, operational errors, ignoring failure symptoms and not repairing an asset when it needs to be taken care, and the skill level of our work force. There is usually a human factor behind most asset failures. Because most failures are caused and do not happen on their own, they are preventable.

If a survey is taken among operations and maintenance personnel as to whether there can be zero failures, the overwhelming answer will be zero failures are theoretically possible, but impossible in an actual work environment. Yes, zero failures are difficult to achieve, but they may not be impossible. If all concerned operations and maintenance personnel set a goal of zero failures and diligently work toward that goal, it is attainable. However, total commitment is needed from all involved, from top management to supervisors and down to the operator and maintainer level. What we need to do is implement some good and best practices, as well as strict adherence to the procedures. The following suggested measures could help in achieving that goal:

a) Operator Involvement

The operator is a key part of a good maintenance strategy. They are close to the assets all the time. They can be the first line of defense against failures, using their natural abilities — four basic sensory tools — to detect any abnormalities:

- Look
- Listen
- Feel
- Smell

They can detect any abnormalities and symptoms at an early stage and get them corrected before they turn into major failures.

O&M personnel can ensure that all the assets are properly secured and bolted. The support structures — piping, hoses, guards, etc. — are not loose and vibrating. These should be properly fastened.

b) Cleaning

Cleaning leads to inspection and timely detection of any incipient failures like cracks and damaged belts. Dirt and dust conceal small cracks and leaks. If an asset is clean, we could see easily if things are not working right, e.g., leaking, rubbing, and bolt loosening, which may be an indication of an incipient failure.

Keep assets and the surrounding area clean. A clean asset creates a good feeling and improves employee safety and morale.

c) Lubricating

Lubrication helps to slow down wear and tear. Check if components are being lubricated properly with the correct type of lubricants and that oil is being changed at the proper frequencies. Don't over-lubricate; use the right amount. Ultrasonic guns can be used to ensure the required amount of lubricant is used. Apply 5S plus or 6S practices to have a lubrication plan, with pictures identifying all lube points and the type of lubricant to be used.

d) Operating Procedures

All operating procedures available at the site should be current. Are these procedures easily understood? Do operators know how to shut down or provide lock out / tag out for the asset safely in case of an emergency? Do they know what operating parameters — pressures, temperature, trip/alarm settings, etc., — to watch? Make sure that operators and other support personnel have a good understanding of the answers to these questions. It is a good practice and very desirable to have these operating instructions laminated and attached to the asset.

e) Maintenance Procedures

Be sure that maintenance / repair procedures are current when used. Maintenance personnel should have the right tools available to perform maintenance correctly and effectively. Having a current procedure is an ISO principle.

When an asset is ready to be repaired, all items identified in the work plan should be staged at the asset site for craft personnel to execute their work in the most effective and efficient manner. Specialized tools should be kept at or near the asset with proper markings.

It is a good practice to laminate the procedures, drawings, part list, wiring diagrams, logic diagrams, etc., and make them available at or near each asset location.

f) Operating Conditions

All assets are designed to operate under specific conditions. Check that assets are operating in the correct environment and are not being misused, i.e., overloaded or unsafely used. If they are not being operated in their designed environment — e.g., they are being used at much higher level of speed than normal use — take steps to see that appropriate safety precautions are being taken and all concerned personnel are aware of the risks involved.

g) Workforce Skills

Ensure that the workforce, operators, maintainers, and support staff are all properly trained and have the right skill sets to operate and maintain the asset effectively. Although ignorance and lack of skill, etc., can be overcome easily by proper training, the human attitude and mindset towards asset failure is somewhat difficult to handle. It takes a lot of effort and time to create the right culture.

h) Repair Documentation

Repair documentation — what we did, with some details — is very important when performing an analysis. We often see entries such as "Pump broke – repaired" or "Mechanical seal replaced." Such entries merely help in maintaining failure statistics, but not in failure analysis.

The challenge is usually how to make data input easy for our crafts personnel. For a good reliability analysis, we need to have quality data to understand how the asset was found before and after the failure, what actions were taken to repair, parts used, and time taken to repair, etc.

i) Designing for Reliability and Maintenance

If the asset is being modified or replaced, make sure that the operators and maintainers are involved with design reviews and are part of the improvement team. The asset should be designed with high reliability and ease of maintenance features. This best practice will be discussed in more detail in later chapters.

3.4 Maintenance Quality and Tasks Optimization

Quality of Maintenance Work

All maintenance work involves some risk. Here, the risk refers to the potential for inducing defects of various types while performing the maintenance tasks. In other words, human errors made during the PM, CBM and CM tasks eventually may lead to additional failures of the asset on which the maintenance was performed.

For example, a review of the data from the power plants that examined the frequency and duration of forced outages after a planned maintenance outage reinforces this risk. The analysis of data showed that in 55% of the cases, unplanned maintenance outages were caused by errors committed during a recent maintenance outage. Most of the time these failures occur very soon after the maintenance is performed. Typically, the following errors or damages may occur during PMs and other types of maintenance work.

- Damage to the asset receiving the PM task may include such things as:
  - Damage during the performance of an inspection, repair adjustment, or installation of a replacement part.
  - Installing material/ part that is defective
  - Incorrectly installing a replacement part, or incorrectly reassembling
- Reintroducing infant mortality by installing new parts which have not been tested
- Damage due to an error in reinstalling asset into its original location
- Damage to an adjacent asset or component during a maintenance task

A quality maintenance program requires trained and motivated maintenance personnel. To create high quality and motivated personnel, the following measures are suggested:

- Provide training in maintenance best practices and procedures for maintenance on specific assets.
- Provide appropriate tools to perform the tasks effectively.
- Get them involved in performing FMEA and RCFA, and in developing maintenance procedures.
- Follow up to assure quality performance and to show everyone that management does care for quality work.
- Publicize reduced costs with improved up-time, which is the result of effective maintenance practices.

Maintenance Task Optimization

Maintenance effectiveness can be improved by optimizing the maintenance work tasks (content) and by effective task execution through the utilization of the many tools available to us. The maintenance tasks — e.g., PM, CBM work instructions, and repair plans — must cover what needs to be done. These tasks can be optimized by using tools and techniques such as FMEA, RCM, and predictive technologies. These tools and techniques can help to optimize the content of the work tasks to be accomplished.

The execution of maintenance tasks can be also optimized by using other tools and techniques such as planning and scheduling, which can help to optimize maintenance resources effectively. All of these tools and techniques will be discussed in more detail in later chapters.

3.5 Measuring Maintenance Performance

Maintenance Key Performance Indicators (KPI)

It is often said that "what gets measured gets done" and "If we can't measure it, we can't improve it." KPIs, also called metrics, are an important management tool to measure performance and help us make improvement actions. However, too much emphasis on performance indicators, or on wrong indicators, may not be the right approach. The selected indicators shouldn't be easy to manipulate just to "feel good." The following criteria are recommended for selecting the best KPI / metrics:

- Should encourage the right behavior
- Should be difficult to manipulate
- Should be easy to measure — data collection and reporting

Metric	Typical	World Class
Maintenance Cost % of ERV	3 - 9 %	2.5 - 3.5 %
Production Loss - Breakdowns	5 - 10 %	< 1 %
Reactive - CM Unscheduled	40 - 55 %	< 10 %
Planned Maintenance	40 - 70 %	85 - 90 %
Overtime	10 - 20 %	< 5 %
Rework - Maintenance Quality	~ 10 %	< 1 %

Figure 3.4 Maintenance Benchmarks

Some key maintenance metrics, with some benchmark data, are listed below in Figure 3.4.

Other maintenance metrics to consider, depending on the maturity of the maintenance program, include:

- PM and CBM effectiveness, or the number in hours of corrective work identified by PM and CBM work divided by hours spent on PM and CBM inspections. The PM and CBM should be able to identify 1/2 – 2 hours of corrective maintenance work to every one hour of PM and CBM performed; otherwise, the frequency or condition parameters should be reviewed or adjusted.

- PM and CBM schedule adherence. It should approximate 90 percent or more.
- Percent of maintenance labor dedicated to performing PM and CBM inspections should be more than 50 percent. The rule of thumb is:
  - PM — Time based 15–20%
  - CBM 30–40%

The distribution may vary depending on type of asset and industry.

3.6 Summary

Maintenance prevents an asset or item from failing and repairs it after it has failed. However, the new paradigm for maintenance is *capacity assurance*, meaning that maintenance assures asset capacity as designed or to an acceptable level.

Maintenance work tasks can be classified in two major categories:

Preventive Maintenance (PM)

- Time (Calendar) based maintenance (TBM)
- Run-based maintenance (RBM)
- Condition-based maintenance (CBM)
- Operator-based maintenance (OBM)

Corrective Maintenance (CM)

- CM — Planned and Scheduled
- CM — Major Repairs / Projects (Planned and Scheduled)
- CM — Reactive (Breakdowns / Emergency)

All maintenance tasks involve some risk of introducing defects of various types while performing the maintenance tasks. In other words, errors committed during the PM, CBM, and CM tasks eventually may lead to additional failures of the asset on which the maintenance was performed. A maintenance quality program requires trained and motivated maintenance personnel.

Maintenance cost and asset availability can be improved by optimizing the maintenance work tasks (content) and by effectively executing tasks through the utilization of tools available to us. Maintenance tasks such as PM, CBM work instructions, and repair plans must cover what needs to be done. These tasks can be optimized by using tools and techniques such as RCM, FMEA, predictive technologies, and Six Sigma. These tools and techniques help to optimize the content of the work tasks to be accomplished. The execution of maintenance tasks can also be optimized by using other tools and techniques such as planning and scheduling. These tools and techniques can help to utilize maintenance resources effectively.

Selecting the right performance indicators to measure maintenance performance is critical and important to implementing best practices. The indicators should encourage the right behavior; they should be difficult to manipulate just to have "feel good" results. Finally, they should be easy to collect and report.

3.7 References and Suggested Reading

- Levitt, Joel. *Handbook of Maintenance Management*. Industrial Press, 1997.
- Mitchell, John. *Physical Asset Management Handbook*, 4th Edition., Clarion Publishing, 2006.
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- Nyman, Don. *Maintenance Management* training notes. Seminars, 1994–96.

Chapter 4

Work Management: Planning and Scheduling

"A goal without a plan is just a wish"
Antoine de Saint-Exupery

After reading the chapter, you will be able to understand:

- Why planning is necessary
- The planning process
- The scheduling process
- Work flow process
- The role of planners, schedulers, and others in managing work
- Work priority
- Turnaround management

4.1 Introduction

Maintenance tasks should be performed efficiently to ensure plant capacity is sustained cost effectively. In the previous chapters, we discussed developing the proper maintenance tasks to keep our assets working. In order to reduce overall operations and maintenance costs, these tasks must be executed efficiently and effectively. Basically this is achieved by eliminating or minimizing avoidable delays and waiting time.

Imagine yourself repairing a leaky faucet or dishwasher at home. Your spouse has asked you repeatedly to fix it. Finally you find the time to take on this assignment. Can you recall the number of times you went back and forth to the garage, to the tool box, or to the hardware store to acquire the correct-sized tool, washer, or seal? It probably took about four or ore hours to finish this task.

Imagine again, a couple of months later, a similar kind of problem occurred. This time you are not available and your spouse calls a plumber. The plumber comes in and assesses the problem, goes back to the truck, gets the right tools and parts, corrects the problem, and leaves in 40–45 minutes. Does this sound familiar? Maybe if you had the right tools and right parts, and better instructions, your task would have taken you under 2 hours instead of 4 hours? The point here is, proper work planning with the right tools, parts, and instructions can save time and avoid wasteful activities.

Figure 4.1 shows a job without planning (sometimes called "on–the-run" planning) and with proper planning. Figure 4.1a shows a disorganized work activity with frequent work interruptions and restarts.

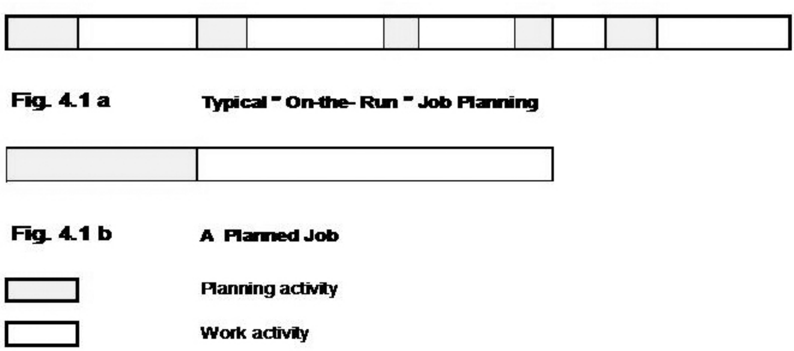

Figure 4.1 Impact of Planning

This example shows evidence of inadequate planning. The frequent work interruptions encountered could be due to lack of availability of right parts, tools, or proper work instructions. A well-planned job with upfront planning and no interruptions is shown in Figure 4.1b. Planned and scheduled jobs take much less time than unplanned jobs.

For many years, industry experts have pointed to the low productivity levels in maintenance departments of many companies around the world. Several studies and survey results reported at major Maintenance and Reliability conferences such as IMC and SMRP have indicated that maintenance craft productivity varies anywhere from 30–50%, or 3–4 hours in an 8-hour shift as an average productive time. Some call this productive time "wrench time," during which maintenance craft personnel actually spend their efforts repairing the assets, as opposed to walking to the store to get the right tools, receiving unclear instructions, waiting for other craft to arrive or release of the asset from operations, and other wasteful activities.

In general, every hour invested in planning saves 1-3 hours in work execution. Abraham Lincoln once said "If I had eight hours to cut a tree, I'd spend six hours in sharpening the axe."

There are, of course, some managers who say they would be thrilled to hear that their maintenance craft workers are sitting idle most of the time waiting for breakdowns to happen. The "Maytag repairman" image of a maintenance department should not be compared to a fire department, where fewer fires to battle are better. A maintenance department can be far more productive in so many ways, becoming proactive instead of responding to emergencies like fire departments. Maintenance departments should be performing preventive and condition-based maintenance tasks, participating in process improvement projects, and working on capital improvement initiatives. Maintenance workers can upgrade their skills, train others, educate operators to run the assets properly to minimize errors. In essence, good planning and scheduling avoids delays and minimizes waiting time, other wasteful activities, and non-productive work.

Planning and scheduling (P&S) is a disciplined approach both for utilizing maintenance resources effectively and for executing maintenance tasks such as PM/CBM or corrective maintenance tasks efficiently. This is accomplished through:

- Defining and clarifying the right work
- Prioritizing work
- Developing the work sequence and steps to complete the task

- Identifying necessary tools, materials, and skills sets
- Assuring availability of materials and assets on schedule
- Scheduling the work to be done with production agreement
- Ensuring details of completed work are documented in CMMS

A work plan is the key deliverable of the planning process. This area is where the most gains in productivity can be made. In some organizations, a single person provides both planning and scheduling functions. In larger organizations, these functions are often split, allowing additional resources for each role.

To move from reactive to proactive maintenance, at least 80% of the work should be planned on a weekly basis. Compliance to this work schedule should be at least 90%.

In this chapter, we will discuss the "what and how" of planning and scheduling maintenance tasks so that they can be executed effectively. Some of the key terms we will be using follow.

Key Terms and Definitions

Bill of Material (BOM)

A list of materials needed to accomplish a particular assembly or fabrication job. The BOM can also be a listing of items necessary to support the operations and maintenance of an asset or component. It contains primarily consumable items and replacement components that may be inventoried as a spare. Oil filters, drive belts, and ball bearings are examples.

CMMS / EAM (Computerized Maintenance Management System / Enterprise Asset Management)

A software system that keep records of all maintenances activities, e.g., maintenance work orders, PM schedules, PM masters, material parts, work plans, asset history.

Coordinator

Oversees the execution of daily operations, including maintenance. They are accountable to the asset or process owner for insuring that the asset or process is available to perform in a safe and efficient manner. Coordinators also help prioritize the work according to the operation needs.

Planned Work Schedule Compliance

The number of planned work orders (and man-hours) completed from the daily/weekly schedule divided by the total number of work orders (and man-hours) on the schedule.

Planner

Develops a work plan to repair or perform a CM or PM for the asset. This plan includes what and how the work will be performed (work description, task sequence, material and tools required, work crew skills, lock-out / tag-out, safety requirements, etc.).

Planning

The process of determining the resources and method needed to perform maintenance work efficiently and effectively. Planning is different from scheduling. In short, planning defines what and how whereas scheduling defines who and when.

Preventive Maintenance (PM) Schedule Compliance:

The number of PM including PdM/CBM work orders completed from the daily/weekly schedule divided by the total number of PM work orders scheduled.

Scheduled Work

The work that has been identified in advance and is logged in a schedule so that it may be accomplished in a timely manner based upon its criticality.

Schedule Compliance

The number of scheduled jobs actually accomplished during the period covered by an approved schedule; also, the number of scheduled labor hours, expressed as a percentage.

Schedulers

Establish daily, weekly, monthly, and rolling yearly maintenance work schedule of executable work in their area. The schedule includes who will perform and when the work will be performed. The schedule is developed in concert with the maintenance craft supervisor and operations.

Scheduling

The process of determining which jobs get worked on, when and by whom, based on the priority, the resources, and asset availability. The scheduling process should take place before the job is executed. In short, scheduling defines when and who execute the work tasks.

Turnaround

A planned shutdown of an asset, process, or total plant to identify and repair major potential problems in a timely manner to improve plant safety and efficiency.

Work Order (WO)

Paper or electronic document specifying the work needed on an asset. A unique control document that comprehensively describes the job to be done, it may include a formal requisition for maintenance, authorization, and charge codes, as well as what actually is to be done.

Work Order Parts Kitting

The collection and staging of parts required for each individual work order. This step usually is accomplished in a plant's storeroom within the maintenance shop. Each kit is identified by a number or label so that it can be staged or delivered to the right maintenance crew.

Work Plan

Sometime called job package. The work plan is prepared by the Planner and includes identification of work to be accomplished, the sequence of work, skills required, special tools, parts needed, and special work instructions needed.

4.2 Work Flow and Roles

Figure 4.2 illustrates a simple maintenance work flow process. There are three types of work:

PM work including CBM/PdM
CM — New work resulting from PM / CBM activities
CM — Breakdown/emergency work (Reactive)

Preventive Maintenance (PM) work should have already been planned and could go directly to scheduling. Corrective Maintenance (CM) – breakdown/emergency work can be executed while bypassing planning, and sometime even the scheduling process based on its urgency. There may not be enough time to plan this type of work. The new CM work identified from PM tasks, including CBM activities, should be planned and scheduled before it can be executed.

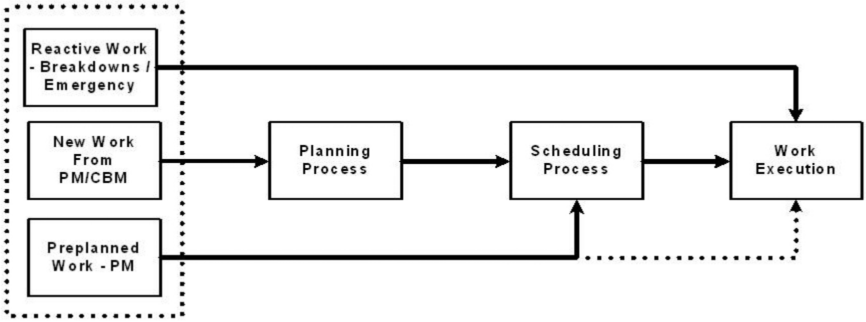

Figure 4.2 Work Flow

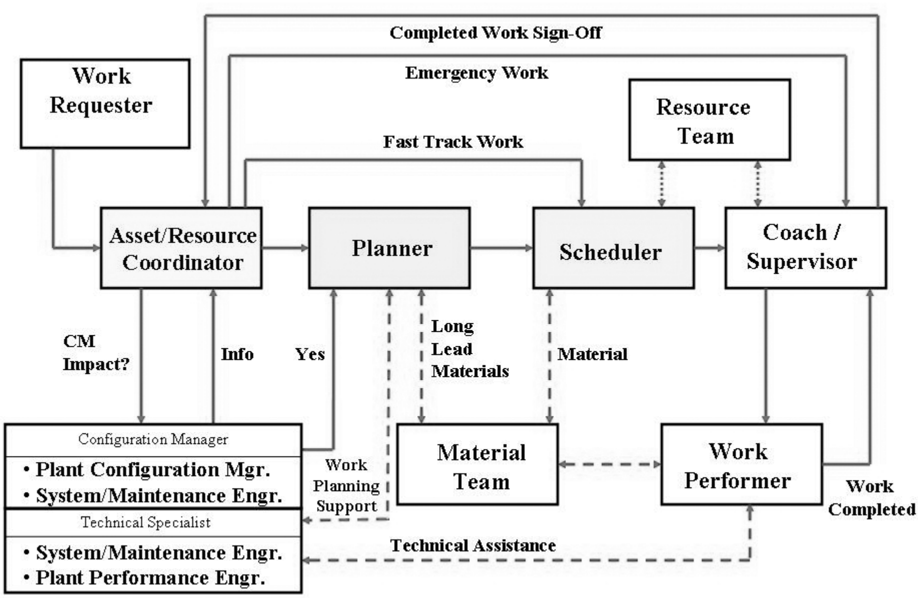

Figure 4.3 Work Flow and Roles.

Figure 4.3 illustrates the work flow and key players in the maintenance work flow process. The following are the key players in this process:

- Coordinator – Asset / Resource
- Planner
- Scheduler
- Craft Supervisor
- Work Performer

In addition, other players such as maintenance / systems engineers and MRO-material personnel play supportive roles in the work flow process.

Initially, the required or requested work task gets routed to an asset / resource coordinator. This person represents the asset owner and may work for maintenance or operations. The coordinator helps to prioritize the work, insuring required resources are in the budget, and to schedule asset outage if necessary. The coordinator forwards the work task to a planner, scheduler, or directly to the craft supervisor or maintenance crew, depending on the task's priority and planning status. For example, PM-type work, which should already be planned, could go directly to the maintenance scheduler. The coordinator may also work with the maintenance engineer or a configuration person for any technical help or if a configuration change request is needed.

As the work order (WO) gets routed from one stage to another, a WO status is assigned based on what's being done to that WO. Figure 4.4 is a suggested list of Work Order Status Codes. In addition, work type, as suggested in Figure 4.5, is also assigned by the coordinator or the planner/scheduler. It is a good practice to code the work orders to help analyze the data for improvements later on.

Work Order Status Codes

Code	Description	Responsible
WC	Waiting for Controller review. This is a default status code	Controller
WE	Waiting for Engineering	Controller / Planner
P	In planning process review	Controller / Planner
PW	Waiting to be planned	Planner
PI	In planning - being planned	Planner
MP	Waiting for material procurement - PO to be issued	Planner/Scheduler
MR	Waiting for material procurement - Material to be received from vendor	Planner/Scheduler
S	In scheduling process	Scheduler
SD	Ready to be scheduled - waiting for "downtime window"	Scheduler
SI	On schedule - weekly/monthly	Scheduler
CP	Job/ WO completed	Supervisor
CW	Job/ WO completed, waiting documentation review	Planner / Engineering
CH	Job/ WO completed, Moved to asset history	Planner / Engineering

Figure 4.4 Work Order Status Codes.

Work Type Category Codes			
Code #	Code- Alpha	Work type	WO Class
1	F	**Failure / Breakdown** : when an asset or a component is down due to a failure or imminent failure which requires maintenance	Corrective Mmaintenance (CM) CM-Unscheduled
2	P	**Preventive Maintenance (PM):** PM inspections of assets to find problems. This includes minor adjustments and replacement of service parts etc.. It also includes CBM routes and data collection.	CM-Scheduled
3	W	**Corrective Repairs:**Corrective repairs made as a result of PM / CBM findings	CM-Scheduled
4	WP	**Capital Improvement Project Work**: The major maintenance improvement work performed under captial projects	CM-Scheduled
5	O	Other miscellenous work needed to improve safety, meeting regulatory compliance or operational needs etc.	CM-Scheduled or Unscheduled

Figure 4.5 Work Type Category Codes.

The maintenance planner plans the job and creates a work plan or job package that consists of what work needs to be done; how it will be done; what materials, tools, or special equipment are needed; estimated time; and skills required. The planner needs to identify long delivery items and work with stores and purchasing personnel to insure timely delivery. A planner may need to work with maintenance / systems engineers and craft supervisors for technical support to insure that the work plan is feasible with sufficient technical details.

The maintenance scheduler in working with the craft supervisor, coordinator, and other support staff, develops weekly, monthly, and rolling annual long-range plans to execute maintenance work. The scheduler is more concerned with when the job should be executed in order to optimize the available resources with the work at hand.

Craft supervisors take the weekly schedule and assign who will do the job on a daily basis. In addition, they also review work plans from an execution point of view and recommend necessary changes in work plans to the planner and the scheduler. It is also their responsibility to

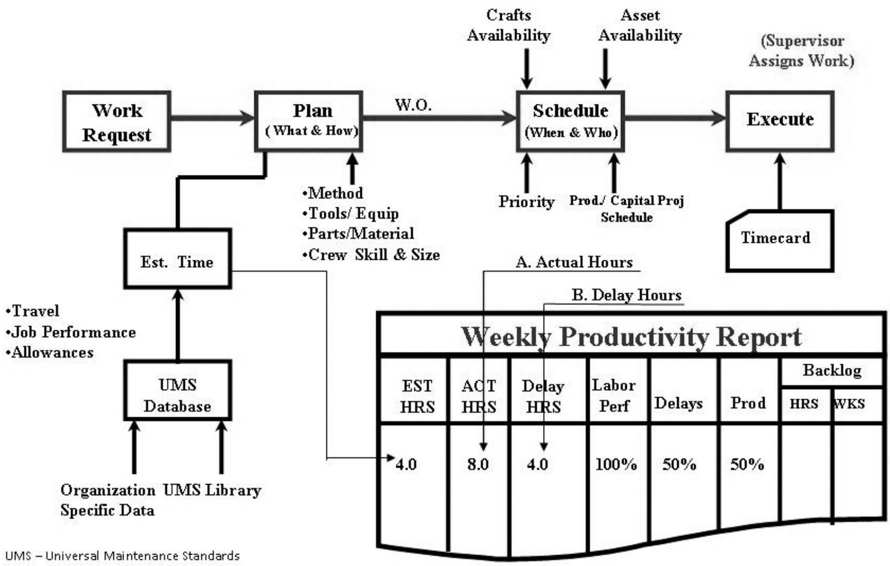

Figure 4.6 Planning and Schedule Process.

ensure that the high work quality is maintained and details of work completed are documented properly in the system.

Figure 4.6 illustrates a planning and scheduling process with its key elements; it includes an example of a productivity report based on delay hours reported.

4.3 Planning Process

"Poor Planning Leads to Poor Performance"
Author: Unknown, but a wise person

Basics of Planning

Planning defines what work will be accomplished and how. Scheduling identifies when the work will be completed and who will do it. Planning and scheduling are dependent on one another to be effective. However, planning is the first step. The ultimate goal of the planning process is to identify and prepare a maintenance craft person with the tools and resources to accomplish this work in a timely and efficient manner. In other words, planning provides maintenance craft workers with everything they need to complete the task efficiently.

Many maintenance engineers and managers consider planning to be nothing more than job estimating and work scheduling. This is not true. Planning is the key enabler in reducing waste and non productive time, thereby improving productivity of the maintenance workforce. Many organizations now have started considering planning to be an important function.

However, they realize that proper planning is not an easy task to do. It takes time to do it right. The time needed to plan a job properly can be considerable, but it has a high rate of return. It has been documented by many studies including Doc Palmer — a noted author of Maintenance Planning and Scheduling Handbook — and the author's own experience that proper planning can save 1–3 times the resources in job execution. If a maintenance job is repeatable, as most are, then it is essential to plan the work properly because it will have a much higher rate of return.

Consider a maintenance shop AB where most of the work is performed on a reactive basis. The shop has no planner or scheduler on the staff. It has:

- 20 maintenance craft personnel
- 0 planner/scheduler
- 1 supervisor
- Est. wrench time = 30%

The estimated productive work available (or performed) /week

= 20 people X 40 hours/week X 0.30
= 240 man-hours /week

Now, consider another maintenance shop XY that has a proactive culture and has demonstrated a wrench time of 55%. This shop has the following staff:

- 18 maintenance craft personnel
- 2 planners / schedulers
- 1 supervisor
- Est. wrench time = 55%

The estimated productive work available (or performed) /week in shop XY

= 18 people X 40 hours/week X 0.55
= 396 man-hours /week

The XY shop has performed 396 – 240 = 156 hours of additional work with the same number of personnel compared to AB shop. This equals a 65% increase in resources or 13 more people on the staff.

Understanding Work

The work to be performed needs to be clearly understood. If the scope of the work has not been defined clearly, the maintenance planner must talk to the requester, visit the job site, and identify what steps, procedures, specifications, and tools are required to perform the job correctly. If the job is too large or complicated, it may have to be broken down into smaller sub-tasks for ease of estimating and planning.

Resource Required and Skill Levels

The skill level of the person required to perform the work must be identified with the estimated hours. The job may include one highly-skilled craft person and one or more low-to-mid-level skilled maintenance technicians. Many times, maintenance professionals believe that it is difficult to estimate the time required to perform a specific job, especially if the skills of the maintenance staff range from very low to very high with everyone theoretically being at the same pay grade and position.

Therefore, planners must have good knowledge of workforce capabilities and the environment. The skill of the maintenance workforce and their basic understanding and knowledge of their trade and plant assets will determine the level of detailed steps and work instructions required in the planning process. Highly-skilled workforce may not need detailed instructions. Job estimating becomes easier and accurate when the jobs are broken down into smaller elements. Long and complex jobs are difficult to estimate as a whole.

A job standards data base such as *Means Standards* or other standard benchmarks can be used to estimate jobs. It is a good practice to build a labor standards library for specific jobs, e.g., removing/installing motors, 5-50HP, 100-500 HP, replacing brake shoes on an overhead crane or forklift, or aligning a pump – motor unit. Predetermined motion times, time studies, and slotting techniques can be used to develop good estimates. An estimate should include work content, travel time, and personal and fatigue allowances.

The following are essential to good estimating practices:

- Familiarity with jobs and plant assets
- Comparing jobs against benchmarks
- Be cautious in using historical data as they may have built-in delays
- Don't try to be very accurate

It is a good practice if the planner is a former senior craftsperson or a crafts supervisor who has been given training in job estimating.

Steps and Procedures

Steps and procedures must be developed with specifications identified to ensure high work quality. The work instructions to disassemble or assemble a complex component should be clear with sketches and drawing as needed. They should include the step at which data such as bearing clearance or temperature reading should be recorded. Human error causes more failures of assets than any other type of error in an organization.

Parts and Tools

Materials, including parts and the kit list, must be identified in order to have the parts available on-site before the job is scheduled. Special tools need to be identified in order to insure the work is completed without delays. For example, does the maintenance person need a torque wrench to tighten a bolt instead of a box end wrench? Furthermore, the torque wrench is of no value if the torque value is not known. Inadequate information may lead to a number of self induced failures. The objective is to reduce the likelihood that an error could occur by using the wrong part or a maintenance person has to stop work to locate the right tools required for the job, as viewed on the following page

It is a good practice to have a planning check list to ensure that all the steps and documentation have been prepared or arranged. Figure 4.7 shows an example of a planner's check list. (See the following pages.)

Typical Job Template for Planning a Maintenance Work (Example)

Work Order Requirement:	Replace Electric Motor (10 HP)
Job Time Standard:	2 hours - duration
	4 Man-hours
	(2 craft person x 2 hour)
Craft Type:	Multi-craft technician or Electrician
Parts Required:	
Part# 11111 Motor, Electric	Location: 22-11-XX

Optional Parts:
(these parts are not required but could be needed if they are worn out)

Part# 2222 Coupling, Flex	Location: 11-00-YY
Part# 3311 Bolts,Coupling (9-16 x 3)	Location: Free Bin, Shop

Special Tools: None

Procedure:

Step 1: Lock out / tag out (see attached procedure for details)
Step 2: Disconnect motor, mark/label wires
Step 3: Unbolt coupling, inspect coupling and remove motor bolts
Step 4: Remove motor using jib crane available
Step 5: Install new motor (check motor is rotating freely)
Step 6: Bolt motor and check for soft foot. – record and correct any soft foot findings
Step 7: Install coupling, bolt motor (torque bolts to xx ft. lbs) and align them using dial gauge or laser within acceptable range +/- 0.xxx (organization standard)
Step 8: Remove lock out / tag out
Step 9: Connect the motor and check for right rotation
Step 10: Test run
Step 11: Clean up and return asset to service
Step 12: Close out the work order detailing what was done

Planner's Check List				
				Checklist Updated as of mm/dd/yy
Work Order #				
Engineering Contact:				
	Required		Status	Comments
Planner Checklist	Yes	No		
Planning Required				
Job / Work Description				
Site Visit				
Past Work History				
Return to Service Requirements				
Job / work plan sequence				
Labor / Craft required				
Craft Timeline / Gantt Chart				
Drawings / Approved Sketches				
Digging Permit				
Environmental Concerns				
Outage request				
Scaffolding				
Special Tools				
Forklift / Vehicle				
Crane - Size Required				
JLG - Size Required				
JSA - Known Safety Items: Asbestos, Lead Paint, TCE, Lifting Plans, Work Permits, Flame Permits, Confined Space etc....				
Weld Review				
Lock-Out Tag-Out (LOTO)				
Material List and Status				
Plan Review - Craft / Engineering				
Miscellaneous Documentation				
Support Work Request #				
Work History				
Scheduler / Expeditor Checklist				
Support Work Request Processed				
Job Execution Package Review				
Material Staged				
Job Execution POC				

Figure 4.7 A planner's check list.

Symptoms of ineffective planning

The following are some symptoms of ineffective planning:

- Maintenance people standing around waiting on parts
- High rework
- Poor work performance
- High stockout in the storeroom
- Planners being used to expedite parts
- Maintenance personnel arriving at the job site and waiting for the asset / system to be shut down (wait is over 15 minutes)
- Frequent trips to storeroom by maintenance personnel
- Production downtime always more than estimated

Enhancing Planning Capabilities

Planning capabilities can be enhanced by ensuring the following:

- Employee involvement and roles. Educate all maintenance stakeholders from a plant manager to the maintenance technician in P&S process to ensure all players understand their role.

- Planners may require additional assistance in developing effective work plans. It is recommended that a senior maintenance technician may be assigned to the maintenance planners for few hours a day. This will help in developing better work plans. Rotating other personnel such as crafts supervisors and senior crafts personnel in planning support job is a good practice. It helps them to understand why planning is important and how it functions.
- Maintenance planners must have a library of information including equipment manuals, drawings, specifications, and specific equipment manufacturer's libraries.
- Planners shouldn't perform additional duties such as temporary or relief supervisors, safety or environmental representative. The planner is not a secretary or clerk.

Planners shouldn't expedite parts for breakdowns or problems. Their responsibility is to insure that future work is planned properly so it can be executed effectively.

- Planners should have technical and hands-on experience as a maintenance technician or craftsman.
- Planned work package, should be reviewed by a craft supervisor to validate that the work package is doable as planned before scheduling.

4.4 Scheduling Process

Understanding Scheduling Basics

Scheduling insures that resources — personnel, material and the asset on which the job is to performed — will be available for maintenance at a specified time and place. Scheduling is a joint maintenance and operations activity in which maintenance agrees to make resources available at a specific time when the asset can be also made available by the operations. Jobs should be scheduled to have the least impact on normal operations.

Once a job has been planned, its status is moved to "Ready to Schedule." Now the job will go to the scheduler, who works with operations and maintenance supervision to develop a schedule that optimizes operations needs with the availability and capacity of the maintenance resources. Organizations use different strategies for scheduling plans. For example, some use monthly, weekly, and daily schedules whereas others use only weekly schedules. Many organizations also maintain a rolling quarterly and yearly schedule. Yearly schedule are usually high-level schedules providing visibility of major outage and turnaround plans. Figure 4.8 shows examples of an organization's integrated scheduling plan structure

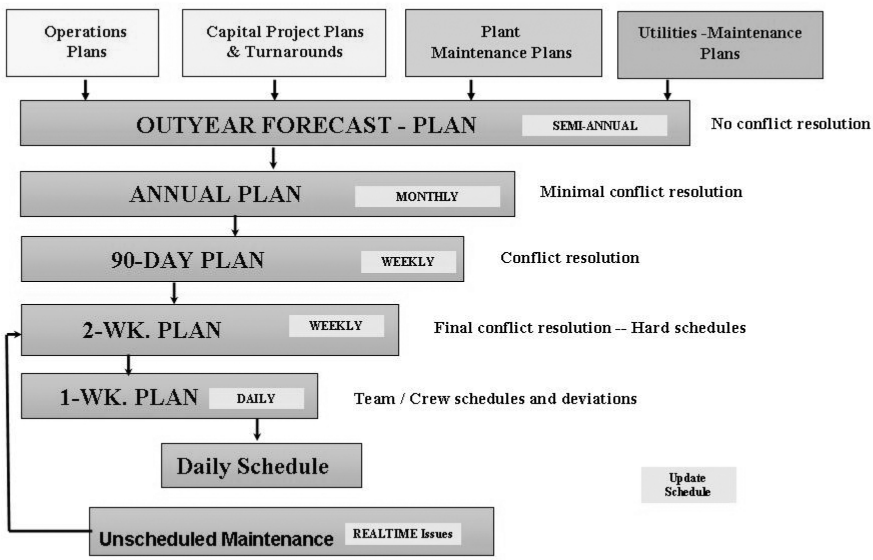

Figure 4.8 Integrated Scheduling Plan.

Schedules are built by assigning dates as requested by the requester. Some jobs need to be re-prioritized to attend the most pressing problems first. Thereafter, the large majority of the available time remaining in the schedule is filled with jobs that are selected in accordance with management's priority, or other important criteria. Preventive maintenance jobs should be given the high priority; they need to be scheduled to meet their due dates.

Once a job is on the schedule, the materials list should go to MRO store for parts kitting and material staging before the specified scheduled date. In many organizations, the CMMS / EAM system does this work automatically. In addition, the job work package will be delivered or made available to the individuals who will execute the job.

When the scheduled time for the job arrives, the maintenance personnel will have every thing they need for the job:

1. A work permit to execute the job
2. Asset ready to be released by operation personnel
   a Ready for lock and tag-out measures
   b. The system already flushed or cleaned if necessary
3. Material / parts on hand (or at site)
4. Right maintenance personnel with proper safety measures — appropriate personal protection equipment (PPE)

There should be no delays when the maintenance personnel arrive at the job site. They should only have to complete the permits and set their own locks of the asset before starting the job. Ideally the job should progress without any hitch; however, there will be some issues. The planner / scheduler should be available to answer any job-related questions and the craft supervisor needs to insure the quality of work.

Doc Palmer, a noted authority in the area of Maintenance Planning and Scheduling, cites six basic scheduling principles:

1. Job plans providing number of persons required, lowest required craft skill level, craft work hours per skill, and job duration information are necessary for effective scheduling.
2. Weekly and daily schedules must be adhered to as closely as possible. Proper priorities must be placed on new work orders to prevent undue interruption of these schedules.
3. A scheduler develops a one-week schedule for each crew based on craft hours available, forecast that shows highest skill available, job priorities, and information from the job plans. Consideration is also made of multiple jobs on the same equipment or system and of proactive and reactive work available
4. The one-week schedule assigns work for every available work hour. The schedule allows for emergencies and high priority, reactive jobs by scheduling a significant amount of work on easily interrupted tasks. Preference is given to completing higher priority work by under-utilizing available skill levels over completing lower priority work.
5. The crew supervisor develops a daily schedule one day in advance using current job progress, the one-week schedule, and new high priority, reactive jobs as a guide. The crew supervisor matches personnel skills and tasks. The crew supervisor handles

the current day's work and problem even to rescheduling the entire crew for emergencies.

6. Wrench time is the primary measure of work force efficiency and of planning and scheduling effectiveness. Work that is planned before assignment reduces unnecessary delays during jobs and work that is scheduled reduces delays between jobs. Schedule compliance is the measure of adherence to the one-week schedule and its effectiveness.

Job Priority

Priority codes allow ranking of work orders to get work accomplished in order of importance. Too many organizations neglect the benefits of a clearly-defined prioritization system. Organizational discipline that comes through communication, education, and management support is key to the correct usage of priority codes.

Many organizations have more than one prioritization systems; however, most of them have been found to be ineffective. The drawbacks of not clearly defining the priorities include:

- Wasted maintenance man-hours on tasks of low relative importance
- Critical tasks being lost in the maintenance backlog
- Dissatisfied operations customers
- Lack of faith in the effectiveness of the maintenance delivery functions

A disciplined method of prioritization will eliminate tasks being done on a whim and instead allow work to proceed according to its true impact on the overall operations of the plant. It will also allow the maintenance delivery function to be executed in a far more effective manner.

Priority System Guidelines

The system needs to cater to the following requirements equally and provide a universal method of coding all works orders.

- Plant-wide asset priorities, allowing for better plant-wide utilization of resources
- Operations requirements
- Improvement projects

Accurate prioritization covers two distinct decision-making processes.

These are.

- Asset criticality
- Impact of task or work to be done on overall operations

The original priority of the work orders needs to be set by the originator of the work order and should be validated by the coordinator. The work originator is the most qualified to answer the questions of asset criticality and impact of the work.

Listings of major assets and their criticality will help in decision-making. Lower criticality items or areas will be easier to recognize.

The following criteria can be used to assign asset criticality and work impact if not corrected.

Asset Criticality

Criticality #	*Description*
5)	Critical safety-related items and protective devices
4)	Critical to continued production of primary product
3)	Ancillary (support) system to main production process
2)	Stand-by unit in a critical system
1)	Other ancillary assets

Work Impact, If Not Corrected

Work Impact #	*Description*
5)	Immediate threat to safety of people and plant
4)	Limiting operations ability to meet its primary goals
3)	Creating hazardous situations for people or machinery, although not an immediate threat
2)	Will affect operations after some time, not immediately
1)	Improve the efficiency of the operation process

Work Priority = Asset Criticality X Work Impact

WO #1: asset criticality of 5 and work impact of 4 gives a priority of 20.
WO #2: asset criticality of 4 and work impact of 4 gives a priority of 16.

In this case,
WO #1 will have the higher priority when compared to WO #2.

The combination of the criticality and impact of the work can be cross-referenced to give a relative weight to each task when compared to all other work.

4.5 Turnaround and Shutdowns

A major downtime that "just happens" can be disastrous for a plant. A planned shutdown can provide maintenance organization an opportunity to identify and address major potential problems or failures in a timely manner to improve plant safety and efficiency. Usually a system or a process is shut down until the requested and specified work is completed and then restarted, thus "turning around" of the process/plant. Examples of this type of work can be relining a large furnace, overhauling and upgrading an assembly system, replacing turbine or compressor blades, cleaning and upgrading a chemical reactor, or replacing process tanks. In a production facility, a turnaround usually consists of combinations of investment projects, maintenance projects or overhauls, and typical maintenance activities such as PMs or corrective maintenance activities that require the plant to be removed from service.

All of the major heavy metal and process industries — steel mills, refining, petrochemicals, power generation, pulp & paper, etc. — have their own nomenclature for their maintenance projects. These are called turnarounds, maintenance shutdowns, planned outages, or just maintenance repair projects.

Shutdowns for scheduled major maintenance work and large capital investments are the most expensive and time-consuming of maintenance projects because of the loss of production and the expense of the turnaround itself. They can be complex, especially in terms of shared resources; as the complexity increases, they become more costly and difficult to manage. Scheduled shutdowns usually are of a short duration and high intensity. They can consume an equivalent cost of a yearly maintenance budget in just few weeks. They also require the greatest percentage of the yearly process outage days. Controlling turnaround costs and duration represents a challenge.

A shutdown always has a negative financial impact. This negative impact is due to both loss of production revenue and a major cash outlay for the shutdown expenses. The positive side is not as obvious; therefore, it is often over looked. The positive impacts are an increase in asset reliability, continued production integrity, investment in infrastructure, and a reduction in the risk of unscheduled outages or catastrophic failure.

Scope management is one of the major challenges in a turnaround. The scope will change, sometimes dramatically, and it will impact the schedule. Usually scope is developed based on information gathered from operating parameters, capital investments, preventive maintenance actions, and predictive tools. Sometimes, we don't have a good understanding of the scope until an asset or system is opened for inspection. As an asset is opened, cleaned, and inspected, the extent of required repairs can be determined and planned.

There are distinct differences between turnaround maintenance work and capital projects. Work scope is well defined in capital projects, but in turnaround, scope is dynamic and fluctuates a lot. Figure 4.9 list major differences between capital projects and turnarounds.

	Capital Project	Turnaround
Scope	Well defined & static- drawings available	Loosely defined, dynamic - changes as inspections made
Planning & Scheduling	Can be planned and scheduled in well advance	Planning & scheduling can't be finalized till scope is approved
Safety permits	fixed, weekly or monthly basis	Requires shift and daily basis due to scope fluctuations
Manpower staffing	fixed, usually don't change much	Variable, changes a lot during execution due to scope fluctuations
Schedule update	Weekly or bi-monthly	Shift and daily basis

Figure 4.9 Capital Projects Vs. Turnaround Maintenance

Identifying and appointing a Turnaround Planner well in advance, maybe six to eight months, is a good practice. This planner helps to develop the scope, integrate the full scope of work including resources, and assure readiness for execution of the turnaround. Similarly, identifying and appointing a Turnaround Manager well in advance, maybe three to four months, is also a good practice. The Turnaround Manager should have the delegated authority to lead the turnaround effort to a successful conclusion. In some organizations, new turnaround managers and planners get appointed just after completion of the last turnaround, as an ongoing process to begin planning for the next turnaround. Lessons learned from the previous turnaround are then transferred to the planning and execution of the next turnaround.

The following is a suggested check list for a turnaround manager:

- Identify the rough scope of the work and resources required, specif ically who will be planning, scheduling, and supervising the work.
- Scope finalization — Work with key players to identify the scope as soon as possible. As a minimum, freeze the scope four weeks before the start of a turnaround, depending on the size and com plexity of the turnaround. There will be changes. Accommodate them as they arise within the contingency allowances of the turn around. Significant additions that exceed contingency plans require revisiting the total scope of the work and authorization of changes by the stakeholders.
- Work planning — Plan the work and prepare job packages with the help of planners and craftsmen who are familiar with the work / area.
- Ensure the work plans have been reviewed by the assigned craft supervisors from an execution point of view.
- Ensure all drawings, repair instructions, and required materials have been identified and updated, and that their availability has been validated. Check that arrangements have been made to stage the material at proper location.
- Check that special tools and lifting devices (e.g., forklifts, mobile crane of right capacity) have been arranged and will be available at site on the scheduled day. Make sure that lift plans, equipment capacity, and condition for service have been validated prior to scheduled lifts.
- Work scheduling — Break large work into smaller work tasks and then schedule them based on resource availability and duration of shutdown. Schedule all work to be completed in 90% of the approved duration. Leave 10% time as a contingency.
- Identify "critical path" tasks that can impact overall schedule and focus your attention to them.
- Make sure all material, including tools and crane, etc., have been arranged to be delivered at least day before the start of shutdown.
- Ensure all the necessary permits have been procured and the lock-out and tag–out plans have been arranged to provide for safe, effi cient access to the scheduled work.

- Establish a communication system. How is work accomplished? Once problems that have been encountered or uncovered, and cor rective action taken, how will this information be communicated and how will feedback be provided in a timely basis? For large and critical tasks, communication may be necessary on every shift. Arrange to meet face to face with task leaders, planners, and schedulers on a daily basis for schedule execution and on a week ly basis to review progress and change in direction, if needed. The schedule is intended to accomplish the overall goals, while main taining enough flexibility to accomplish minor changes.
- Arrange a face-to-face meeting with all your key players, includ ing operations personnel, to discuss the goal and schedule of this shutdown. Make sure they understand the cost of this undertaking and impact of delays. Emphasize safety and quality of work. This meeting should be held a few days before the start of the shut down. As a minimum, the Operations personnel should be includ ed in the weekly progress reviews.
- On the first day of the shutdown, make sure all safety measures are taken in shutting down the system and that appropriate personal protection equipment (PPE) are used. All lock-out and tag-out should be completed properly.

Attention to the following items may be required and appropriate corrective action planned:

- **Barricades**. These should be considered to restrict the movement into or the presence of people in restricted area where overhead lifting, high voltage, radiography, and hazardous materials may be present. Ensure that proper safety signs are displayed in appropriate areas.
- **Dust Control Management.** A large shutdown can also be the source of excessive dust, depending upon the area and work to be accomplished. Make necessary arrangements to control the dust.
- **Emergency Showers and Eye Bath.** Make certain that emergency showers and eye baths are available at the right locations.
- **Liquid and Solid Waste Handling.** Certain cleaning operations may create liquid and solid waste which can be handled within the in-plant industrial sewer system. Other wastes — including asbestos, spent chemicals, sandblast media — may

create materials that require special handling, disposal, and access limitations. Unanticipated disturbance or creations of hazardout materials are show-stoppers often overlooked during the planning process. Develop or review policies for spill control, and containment and disposal of hazardous material including potential handling problems

- **Noise Control.** Some repair steps may generate excessive levels of noise. These operations need to be identified and corrective action taken that may require use of ear plugs and posting of "High Noise" area.
- **Scaffolding Control.** During a shutdown, scaffolding is often moved from one location to another. The probability of it mixing with other sources is very high. Ensure all scaffolding from different sources is properly marked and color coded if necessary. Portable, motorized that lift devices add significant flexibility to any scaffold plan for large turnaround.
- **Ensure that "return to the service" is well planned.** What are the critical items that needed to be right before system can be turned over for start-up? Involve Operations personnel in developing and executing the return to service plan, inte grating their standard operating procedures with special con cerns involving new or modified equipment. Make sure those critical items are OK. The right sequence of operation and energizing electrical devices safely is very important.

Holding a Post Turnaround Meeting is one of the last important tasks for the turnaround manager. The area of turnaround planning that is most often underestimated is the area of lessons learned. Assuming the Manager and Planners keep good meeting notes or logs during the planning and execution phases, these notes provide excellent sources of lessons learned and process improvements for future turnarounds.

The time to collect this information is throughout the entire duration of planning and executing the turnaround. The lessons learned are compiled and reviewed with the turnaround team and stakeholders in a post-turnaround session. The purpose of the meeting is to discuss what worked and what did not work in the turnaround process while the memories of the turnaround are still fresh in everyone's mind. Recommenda - tions from the team are then woven into the process for future reference and implementation.

4.6 Measures of Performance

The planning and scheduling processes, like other processes, need to be measured and evaluated to make improvements. A few examples of performance measures and benchmark data include:

1. **Percentage of planned work.** This measure is the percentage of all scheduled jobs that have been planned. It assumes that all parts, procedures, specifications; tools, drawings, etc., have been identified before the job is scheduled. The benchmark is 90%.
2. **Percentage of schedule compliance.** This measure is the percentage of work accomplished that is agreed upon or on the weekly schedule.
3. **Percentage of time that kits (materials and parts) are delivered on time**. This measure is calculated as the number of times the kits (material and parts) were delivered on time divided by the total number of kits delivered. This percentage affects the planner's ability to plan jobs properly. Expediting parts adds unnecessary and wasteful cost to the P&S process.
4. **Percentage of time the right part (s) is delivered**. As part of the planning process, planners and schedulers should have the confidence that a specific vendor will deliver the right part when required. Otherwise this problem could create a delay in performing the work. The benchmark is 99.0% or higher.
5. **Percentage of work from a formal work PM/CBM**. Most work should come from identifying the degradation of a component or asset far enough in advance of any PM/CBM tasks that the job can be planned and scheduled properly, thus minimizing unexpected delays and production loss.
6. **Percent Rework.** This measure is the percent of work orders requiring rework. Each organization needs to define what rework means to them. It may differ from one to another organization. Examples of rework include revisiting an asset to fix something within 7, 15, or 30 days of PM or a major repair work performed. The benchmark number is less than 2%.

4.7 Summary

Planning and scheduling have the most impact on timely and effective accomplishment of maintenance work. The planning and scheduling functions are the center where all maintenance activities are coordinated. Although planning and scheduling are closely related, they are two distinct functions.

- **Planning**: ***what and how***
- **Scheduling**: ***when and who***

Planning is what and how to do the job. It's an advanced preparation of a work task so that it can be executed in an efficient and effective manner some time in future. It involves detailed analysis to determine and describe the work to be performed, task sequence, and identification of required resources — including skills, crew size, man-hours, spare parts and other service materials, special tools, and any lifting device or equipment needed. It also includes identification of special lock-out and tag-out or any special permit required before the start of the task.

Scheduling is when and who is going to do the job. It's a process by which resources are allocated to a specific job based on operational requirements and resources availability.

Planning and scheduling eliminates or minimizes the waiting time and delays. When maintenance personnel have to return to the store room numerous times to locate the required parts, or to locate a specific tool, it delays the work execution and adds additional cost to the job. Poor planning and scheduling lead to poor utilization of maintenance resources.

4.8 References and Suggested Reading

- Kister, Timothy and Bruce Hawkins. *Maintenance Planning and Scheduling Handbook*. Elsevier Science & Technology, 2006.
- Nyman, Don and Joel Levitt. *Maintenance Planning, Scheduling and Coordination*. Industrial Press, 2001.
- Palmer, Doc. *Maintenance Planning and Scheduling Handbook*, 2nd Edition. McGraw-Hill, 2005.

Chapter 5

Materials, Parts, and Inventory Management

Almost all quality improvement comes via simplification of design, material, manufacturing layout, processes, and procedures.
Tom Peters

After reading the chapter, you will be able to understand

- Maintenance store operations
- Types of inventory
- Tools and techniques to optimize inventory
- How to ensure availability of parts and materials on time
- Key performance measures

5.1 Introduction

Maintenance storerooms play an important role in supporting the maintenance function. The objective is to provide the right spares and service parts and supplies at the right time in the right quantities. If the right part is not available when needed, the repairs will have to be delayed. delayed. Any delay in restoring a failed asset will increase the maintenance and operations costs. Thus, a storeroom may be considered a very important enabler in reducing the maintenance cost.

It is not uncommon to see maintenance technicians spending a considerable amount of their time, as much as 20–30% in a shift, hunting for the right parts. To provide the best possible support for the maintenance technicians, a reasonable amount of spare parts and materials must be on available on stock. Readily available spare parts will enable emergency repairs on a timely basis. Availability of routine adequate supplies such as lubricating oil, gaskets, and others will facilitate the performance of scheduled routine maintenance. Items that are very expensive and not routinely stocked may be purchased when needed to reduce the inventory carrying cost.

In many manufacturing and support facilities, the budget for spare parts can be a significant percentage of the total maintenance budget. This level may be justified because of the fact that non-availability of the spare parts could substantially increase the cost of taking care of failures. It is inconceivalble and impractical for a maintenance department to carry all the required spares in stock. This is prohibitively expensive. Therefore, managing inventory of spare parts, supplies, and tools is a very important function in maintenance and reliability. Usually quantitative decision techniques for determining when and what to buy are used. An overview of quantitative techniques available for reducing inventory costs is presented in this chapter.

In practice, application of these techniques have produced the following results:

- 20% reduction in the workload of maintenance planners
- 30% reduction in the number of purchase orders for replenishment parts
- 40% reduction in manually-prepared direct purchase requisitions
- 30% reduction in maintenance storeroom inventories
- 20% reduction in total maintenance costs

A maintenance storeroom, also called an MRO storeroom (maintenance repair and operations), is responsible for the following functions.

- Provide the right spare parts, supplies, and tools
- Deliver the needed items to the right location at the right time.

These major responsibilities of a maintenance storeroom may be met with good advanced planning based on best practices. However, for certain parts, these expectations could be unrealistic due to cost, unexpected high failure rates, and high lead time. Maintenance, engineering, purchasing, and management must work together in developing a plan to determine the most economical stocking levels for the critical items. Some items have small or negligible lead times and can be bought with very little loss of time; as such, these items probably do not have to be stocked.

The right time to decide what parts and material should be stocked, and in what quantity, is before placing an asset or system in service. The manufacturer of the assets and systems usually provide a recommended list of spare parts as well as a preventive maintenance program based on a Failure Mode and Effects Analysis[1] (FMEA). The failure modes and frequency of failures should optimize the spares list and provide a good estimate of what and how many are required to be stocked during a specified period.

Placing an order has costs because the process requires writing the specification and identifying the potential sources. After the sources are identified, bids are invited and a qualified vendor is selected. These functions, which cost money, are called the ordering costs. The cost of stocking an item and holding it in inventory could be as much as 30% of item cost per year. The next few sections cover different techniques that can be applied to reduce the inventory costs.

Some key terms related to materials and inventory management are listed below:

Key Terms and Definitions

Bill of Materials (BOM)

A list of all the parts and components that make up a specific asset.

Commonly-Used Parts

A combination of standard replacement parts and hardware items that may be used on many equipment and assets.

CMMS (Computerized Maintenance Management System)

A software package that assists in the asset and work manage-

1 — FMEA is a tool to identify failure modes; it is discussed in more details in Chapter 11..

ment functions. It's a data-based, decision making tool to optimize these functions.

Emergency Spares / Parts

Replacement parts required for critical assets and equipment that are kept in reserve in anticipation of outages caused by man-made or natural disasters. The demand for these parts is unpredictable. Usually their cost is high and they have long lead times to procure. Not having these parts in stock may result in extended downtime and major production loss. Sometime these spare parts are called insurance spares.

Inventory Turnover Ratio (or Inventory turns):

This ratio tells how often an inventory turns over during the course of the year. Because inventories are the least liquid form of asset, a high inventory turnover ratio is generally positive. However, in the case of MRO inventory, the inventory turnover ratio is usually low, less than two.

Inventory turns = Inventory issued in a year / Average inventory

Average inventory = (Beginning inventory + Ending inventory) / 2

Just-in-Time Inventory (JIT)

A method of inventory management in which small shipments of stock are delivered as soon as they are needed. JIT minimizes stocking levels.

MRO

Maintenance, Repair, and Operations. Sometime "O" is referred to as Overhaul.

MRO Store

Maintenance, repair, and operations store; it stocks all the material and spare parts required to support maintenance and operations.

Service (Self-Service) Stock

Commonly-used parts and maintenance supplies kept nearby in high maintenance areas or outside the storeroom. Withdrawal of this stock requires no requisition or paperwork. Sometimes referred to as Dime Store.

Spare Parts

Replacement items found on the CMMS bill of material may or may not be kept in inventory to prevent excessive downtime in case of a breakdown.

Stock Keeping Unit (SKU)

An inventory management term for individual stock items carried in inventory, with assigned inventory numbers.

5.2 Types of Inventory

The traditional vocabulary definition defines inventory as the quantity of goods or material on hand. All inventories are not alike. For example, retail or consumer inventory includes TVs, clothing, cars, and groceries whereas production or operations inventory includes pumps, motors, steering wheel assemblies, valves, steel plates, and spare parts that are vital to the plant operations.

Inventories in a production process are often broken down into four categories: 1) finished goods, 2) work-in-process, 3) raw materials, and 4) maintenance and operating items such as spare parts and operating supplies, including consumables. The spare parts, consumable items such as filters, safety gloves, and other materials that are required to keep assets operating in a plant are the focus of this chapter.

The maintenance inventory meets emergency, short-term, and long-term maintenance requirements to keep the assets operating. Inventory is a hedge against the unknown. If we knew exactly when a part was required, we wouldn't need to carry it in stock. We would simply buy the part and have it delivered exactly when needed. This view sounds good in theory, but because we don't know exactly when we'll need that part, we have to carry it. Thus, inventory is sometimes called "buffer stock against use."

Inventory also protects us from the uncertainties of delivery. If we knew exactly when a supplier would deliver our order, we would never need to have inventory to cover for erratic delivery schedules. Suppliers have problems, too. Thus, inventory is sometime called "buffer stock against delivery."

Buffer stock, also called safety stock or level, can and should be kept to a minimum by applying practices and techniques discussed later in this chapter.

Inventory Classifications

Inventories can be classified in three major categories based on their usage rate:

1. Active inventory
2. Infrequently used inventory
3. Rarely used inventory

Active Inventory (AI)

Active Inventory includes items that are used frequently enough that future demand can be predicted with good accuracy. If an item or part is used at least once a month, it is considered an active inventory item.

Active items are:

- Smaller spare parts e.g. standard bearings, oil seals
- Commodity or supply items e.g. — safety gloves, bathroom supplies
- Items that have generally high demand each month
- Predictable future demand

Infrequently Used Inventory (IUI)

These are the items which are infrequently used, usually less than 10 times per year, but the demand still can be predicted with some accuracy.

Rarely Used Inventory (RUI)

These are items that fall into the category of "Must Have." These parts are almost impossible to obtain or lead time to acquire them is so long that it often seems we can't get them. They sit on the shelves, and there is little we can do about it. The vast majority of MRO store items fall into this category. An analysis of 100 MRO stores indicated that 50% or more items had no usage during the past two years. Yet, most of these items must be on hand when needed.

A typical MRO Inventory profile of more than 100 plants is shown in Figure 5.1. Over 80% of the items in a typical MRO store can be classified as infrequently and rarely used items, as shown by the first bar in the figure.

In order to reduce the costs of RUI items, some organizations have started to team up with other organizations in their area to share high value RUI items such as large motors, valves, and transformers.

The middle and right bars in Figure 5.1 represent the percentage of inventory value and the percentage of transactions that are for active items vs. infrequently and rarely-used items.

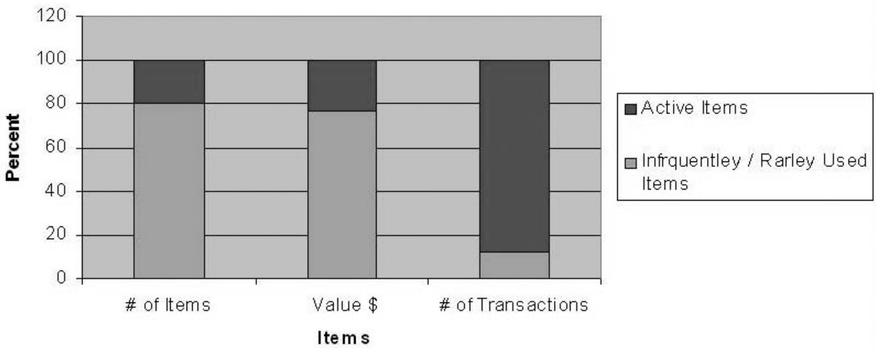

Figure 5.1 Materials, Parts, and Inventory Management.

ABC Analysis (Inventory Stratification)

ABC analysis, also sometimes called inventory stratification, is another technique used to classify and optimize inventory levels. In this technique, inventory is classified based on an item's value and usage rate. This classification system is used to distinguish between the trivial many and the vital few. In fact, this classification system reflects the Pareto principle.

Most of the items in classification A are one-of-a-kind parts with long delivery, high cost, and low demand. They may cost over $500/unit to as much as $100,000 or more — for example, a large 10,000 HP electric motor required for a critical operation. Items in this classification are usually most critical. Their demand is difficult to predict and unavailability can cause long downtime/shutdown. These items are needed in order to have good inventory control. It has been found that the number of inventory items in this category usually range from 10–20% of all items, averaging 15%. Their cost, however, range from 60–80% of total inventory cost. They can be compared to Rarely Used Inventory (RUI) discussed earlier.

Items in the B classification are standard parts that may be stored in vendor's warehouses and made available by local distributor in a few days to a few weeks. Usually these items are mid-to-high cost, possibly $100/unit or more. Items in this category are less critical and infrequently used. Their future demand can be predicted with some effort.

It has been found that in the B category, the number of items usually ranges 20–35%, averaging 25% of all inventory item. Their cost ranges 15–25% of all costs. They can be compared to Infrequently Used Inventory (IUI) discussed earlier.

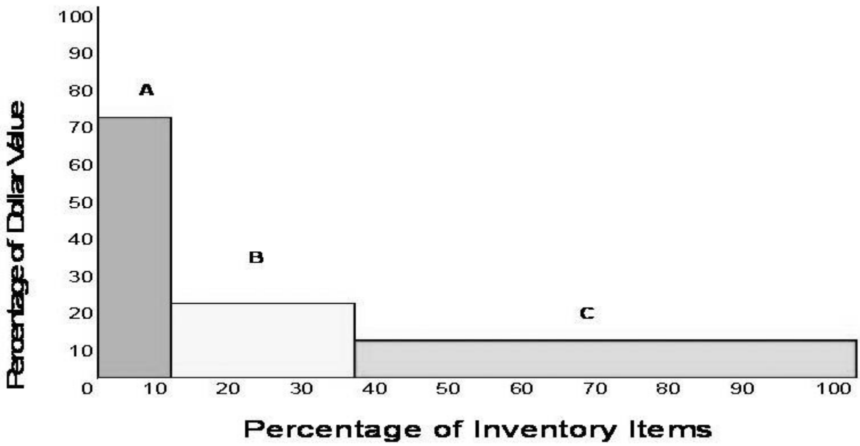

Figure 5.2 ABC analysis.

Figure 5.2 shows a typical ABC inventory analysis and value stratification.

Most of the items in the C classification are standard parts — consumable or commodity items that can delivered by the vendor on a regular schedule or made available by local distributors a in few hours or a couple of days. Usually they cost less than $100/unit. Items in this category are actively used; their future demand can be accurately predicted and may not need inventory control.

It has been found that in category C, the number of items range 55–75%, averaging 65% of all items. Their cost ranges 5–15% of all costs. They can be compared to Active Inventory (AI) discussed earlier.

A typical inventory stratification example is shown in Figures 5.3 and 5.4. Figure 5.3 shows 20 items with their unit cost and their demand rate for the current and last three years. Figure 5.4 then shows each item's classification category and current cost as well as the percent of items in each category and their costs. The objective of this analysis is to move items from category A to B and from B to C in order to minimize inventory costs.

Criteria used to classify items in this example, see Figure 5.3:

A items = Value over $1,000 and usage less than 6/year
B Items = Value of $100–999 and usage rate over 6/year
C items = Value below $100 and usage rate over 12/year

Part #	Part Description	Unit Cost $	ABC Classification	Annual Demand Past year	Past 3 years Demand	Current Stock	Total Current Cost
10001	Bearing, roller xxxxxx	$85.00	C	50	100	29	$2,465.00
10002	Gloves, Safety	$15.00	C	120	400	60	$900.00
10003	Oil Seal, xxxxx	$6.50	C	40	100	38	$247.00
10004	Slings, wire rope #abc	$370.00	B	5	10	4	$1,480.00
10005	Slings, wire rope #xyz	$850.00	B	3	5	4	$3,400.00
10006	Wire rope Crane # xxxx	$1,450.00	A	0	1	2	$2,900.00
10007	Bearing, Spepherical xxxx	$180.00	B	8	6	6	$1,080.00
10008	"O' rings - misc sizes kit	$1.90	C	200	680	80	$152.00
10009	Hydraulic Cyclinder Repair Kit	$48.00	C	18	40	20	$960.00
10010	Hydraulic Cyclinder # xxxx	$860.00	B	6	10	4	$3,440.00
10011	Motor, elec , zzzzzHP	$8,400.00	A	0	1	2	$16,800.00
10012	Motor, elec , xxxxxHP	$48,000.00	A	1	2	1	$48,000.00
10013	Valve, servo # xxxxx	$1,250.00	A	4	3	4	$5,000.00
10014	Utility Supply misc.	$1.30	C	600	2000	340	$442.00
10015	Gearbox # xxxxxxx	$2,600.00	A	1	0	2	$5,200.00
10016	Pump-motor unit xxxx	$180.00	B	15	40	18	$3,240.00
10017	Pump Hyd xxxx	$680.00	B	4	10	5	$3,400.00
10018	Bearing, friction roller # xxxx	$120.00	B	24	90	20	$2,400.00
10018	Misc . Fittings	$3.20	C	200	1000	160	$512.00
10019	Card, Circuit board xxxx	$110.00	B	60	100	30	$3,300.00
10020	wire, electrical roll, misc	$105.00	B	14	20	18	$1,890.00
	Total					847	$107,208.00

Figures 5.3: Inventory costs.

Classificatio	Part #	Part Description	Unit Cost $	Annual Demand Past year	Past 3 years Demand	Current Stoc	Total Current Cost	Sub Total	COST	# of ITEMS	% ITEMS
A	10006	Wire rope Crane # xxxx	$1,450.00	0	1	2	$2,900.00				
A	10011	Motor, elec , zzzzzHP	$8,400.00	0	1	2	$16,800.00				
A	10012	Motor, elec , xxxxxHP	$48,000.00	1	2	1	$48,000.00				
A	10013	Valve, servo # xxxxx	$1,250.00	4	3	4	$5,000.00				
A	10015	Gearbox # xxxxxxx	$2,600.00	1	0	2	$5,200.00	$77,900.00	73%	11	1%
B	10016	Pump-motor unit xxxx	$180.00	15	40	18	$3,240.00				
B	10017	Pump Hyd xxxx	$680.00	4	10	5	$3,400.00				
B	10018	Bearing, friction roller # xxxx	$120.00	24	90	20	$2,400.00				
B	10019	Card, Circuit board xxxx	$110.00	60	100	30	$3,300.00				
B	10020	wire, electrical roll, misc	$105.00	14	20	18	$1,890.00				
B	10004	Slings, wire rope #abc	$370.00	5	10	4	$1,480.00				
B	10005	Slings, wire rope #xyz	$850.00	3	5	4	$3,400.00				
B	10007	Bearing, Spepherical xxxx	$180.00	8	6	6	$1,080.00				
B	10010	Hydraulic Cyclinder # xxxx	$860.00	6	10	4	$3,440.00	$23,630.00	22%	109	13%
C	10018	Misc . Fittings	$3.20	200	1000	160	$512.00				
C	10001	Bearing, roller xxxxxx	$85.00	50	100	29	$2,465.00				
C	10002	Gloves, Safety	$15.00	120	400	60	$900.00				
C	10003	Oil Seal, xxxxx	$6.50	40	100	38	$247.00				
C	10008	"O" rings - misc sizes kit	$1.90	200	680	80	$152.00				
C	10009	Hydraulic Cyclinder Repair Kit	$48.00	18	40	20	$960.00				
C	10014	Utility Supply misc.	$1.30	600	2000	340	$442.00	$5,678.00	5%	727	86%
		Totals				847	$107,208.00	$107,208.00		847	

Figure 5.4 ABC results.

The criteria should be tailored to meet your needs, environment, and type of inventory.

Figure 5.4 shows the data after ABC analysis. Again, our objective is to review item cost and usage (or demand) on a regular basis in order to reduce the number of items to stock in the store without impacting the maintenance needs.

Data in this table indicate the following: 11 items in Category A with 73% of the total cost; 10 parts, 109 items in Category B with 22 % of the total cost; and 7 parts, but 727 items in Category C with only 6% of the total cost. Obviously, efforts attributed towards A items should be greater than that for C items. Items in Category A should be reviewed frequently whereas Category C can be reviewed with lesser frequency.

Another type of inventory — hidden stock — covers those items that mechanics stash under conveyors and stairwells, inside cabinets, and in toolboxes. This is the material called "lost" each year when physical inventory is done. It's a real problem because the condition of those parts is unknown when the mechanic finally uses them. If the parts are bad, a costly second downtime period may be needed to fix the asset correctly. Usually organizations that have high hidden stocks have a reactive culture.

You may also have items in store which can't be classified. They are dead stock. They may be spares for assets that were removed long ago. Can this dead stock be sent back to the supplier or one of the customers? Other solutions are to sell it to a surplus operator or for scrap, or just trash it. Dead stock still takes space to store and the organization has to pay inventory taxes too. In some states, businesses have to pay property taxes that cover inventory. Remember too that it costs, on average, 25% per year to store the material.

5.3 Physical Layout and Storage Equipment

The physical layout of the store is an important factor in gaining productivity. Two issues are involved in this decision: the location of the maintenance store itself and the location of parts and material within the store.

The maintenance store should be located as close as possible where work is performed — near the assets. Most of the time, a maintenance store becomes a hub of maintenance activities. The physical layout of the storeroom should be planned for efficient material flow. To ensure that the store room is run efficiently and effectively, the layout should consider the following:

- The store room should be separated from the main plant operations either by walls or with a secured cage. The secured area is required to discourage pilferage of tools and expensive items. Many organizations have started using access cards issued to each employee. The card provides controlled access to the store room as well as the tool crib. Nevertheless, organizations need to make sure that any material issued gets charged to the right asset and project.
- The parts-materials area should be sized and equipped appropriately for the type of parts-material to be stored. Keep heavy parts down, close to or on the floor.
- Parts that are slow movers should be stored in the back of the storeroom, and fast movers in the front for easy and fast access. Consumable items and low-value items such as bolts, nuts, fittings, filters, and gaskets that may be needed for frequent maintenance tasks should be located near the front of the storeroom or outside the storeroom for easy access.
- Oil supplies should be kept away from the main storage area. Any oil supply area needs to be designed to meet all fire and environmental safety requirements.
- Each storage location and parts storage bin should be properly labeled
- The storage area should be free of clutter and debris to ensure personnel can move around to access the parts easily. There must be sufficient lighting in the area so that store personnel and maintenance technicians can easily see and count the parts.
- Like a retail store, the MRO storeroom will receive returns. Sufficient space should be available to handle returns. A smooth process for accepting and accounting these returns must be implemented.

Figures 5.5 shows on the left a disorganized store room. It will be difficult to find an item in this store. On the right side clearly a well-maintained storeroom. A typical material flow in a facility with an MRO storeroom is shown in Figure 5.6. When designing the storeroom, ensure that material flow is smooth and reduces travel and procurement time.

Parts – Material Storage and Retrieval System

There are many different storage and retrieval methods that can be used to handle parts and materials in the storeroom. Use of each method will depend on the characteristics of the part and its demand.

Figure 5.5 Disorganized and well-maintained storerooms.

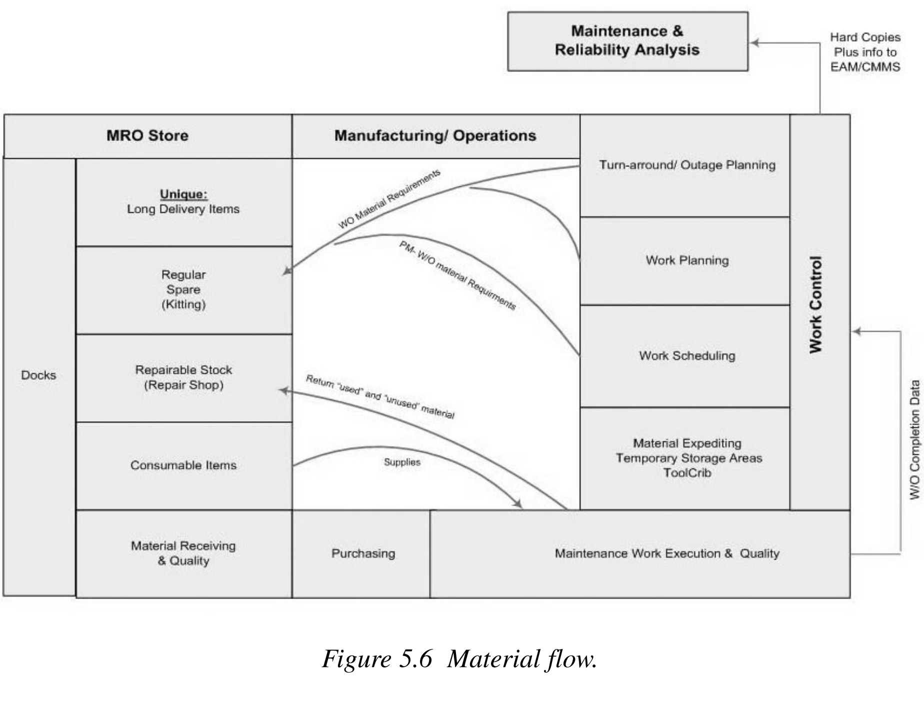

Figure 5.6 Material flow.

Storage Equipment

Parts storage equipment can generally be broken down into two main categories: *man to part* and *part to man*. The first category, man to part, will be most familiar to MRO personnel and consists of storage standbys like pallet racks, shelving, and bin storage. In this arrangement, we go to the part to pick it. This arrangement is very common in small MRO stores.

In part to man arrangement, the part comes to us. With the advent of system-directed storage, and particularly when integrating with production and distribution storage, part to man systems — such as horizontal and vertical carousels, and Automated Storage and Retrieval System (AS/RS) — have become viable. They may offer significant improvements in MRO parts storage efficiency.

Man to Part

Man to part storage systems are the mainstay of MRO parts storage. Initially cheaper than automated part to man storage systems, they can provide dense part storage. Of the two types, man to part is easier to manage manually. On the downside, this type of storage (by itself) does not provide part check-in / check-out control and inventory tracking, which can lead to lower inventory storage accuracy. The three major types of man to part storage are described below:

Shelves/Bins Installed at some level in virtually all parts storage areas, shelving and bin storage is perhaps the most common type of MRO part storage. It is most appropriate for smaller, slower-moving parts not accessed on a regular basis. Available in numerous configurations and styles, shelving and bin storage will always have a place in MRO parts storage methodology.

Pallet Rack The big brother to shelving and bin storage, pallet rack is the second most common type of MRO parts storage. It is used primarily for parts that are too big or too heavy for shelving. Pallet rack storage has the common advantage of having a low initial install cost and virtually no maintenance; it is very configurable. Negatives include a lower storage utilization density than shelving or modular drawers. Furthermore, either rack decking or actual pallets are required for storage on the rack beams.

Modular Drawers Modular drawer storage consists of lockable storage cabinets containing multiple custom-divided drawers that closely match the specific part/tool configuration requirements. Particularly well suited for small part storage and tool storage, modular drawer storage can provide very high-density, secure storage. Best utilized for very slow moving parts or as a dedicated location for secure tool storage, the custom-configured nature of this type of storage makes it less suited for constant access and random part storage. Modular storage cabinets are generally more expensive than standard shelving. Some level of systematic tracking, rather than simple paper records, is often required to manage large numbers of modular storage cabinets. However, the extreme storage density and security of modular drawer storage makes it a consideration for use in all MRO storage strategies.

Part to Man

Part to man storage systems are usually automated storage devices that offer several advantages over standard man to part methods. These advantages include controlled access that provides more part protection and security, check-in / check-out processes that aid in access supervision and tracking, and ease of access to a greater vertical dimension. This last feature often results in more effective storage density per square foot of floor space.

One of the major disadvantages of part to man systems is high initial cost. Automated storage systems are more difficult to reconfigure than more traditional storage methods; they also have an on-going maintenance cost associated with their use. Regardless of configurability and upkeep concerns, the high initial cost of these systems has been most responsible for the relatively low numbers of automated storage equipment in use for MRO stores. With the advent of integrated systems, and the resulting ability to combine MRO stores with production and inventory stores, this investment cost is not specific to maintenance and can be spread across other department budgets. This ability to spread investment costs across departments has resulted in an increase in the use of automated storage systems and warrants their inclusion in any discussion of planned MRO storage.

Horizontal Carousels Horizontal carousels consist of multiple sections of shelving (often called "bins") mounted on a revolving track system (Figure 5-7left side). Control for these systems can be manually or systematically directed. Often the least expensive of the automated systems,horizontal carousels are becoming increasingly common for both general inventory and MRO parts storage.

Vertical Carousels Similar to horizontal carousels, vertical carousels consist of shelving layers (often called "pans" or "trays") mounted on a vertically-revolving track system (Figure 5.7right side). Generally constructed with a solid metal enclosure, vertical carousels provide a very secure environment for high-value parts storage.

Figure 5.7 Horizontal Carousels and Vertical Carousels.

No matter which storage, retrieval, or parts identification technology is used, the important issue is that the parts–material usage history must be analyzed to determine the movement. Each alternative will have a different payback as labor and productivity savings offset the capital investment.

5.4 Optimizing Tools and Techniques

Computerized Inventory Control System

Most Computerized Maintenance Management Systems (CMMS) and Enterprise Asset Management (EAM) systems have a built-in inventory management system. Each item is recorded in the CMMS system when it is purchased or issued on a work order and gets charged to specified equipment.

Parts are assigned locations in the inventory management system of CMMS/EAM, and a physical inventory verifies quantity and location. CMMS/EAM systems can usually generate a physical inventory form sorted by location, bin, and part number, description, etc.

A process should be set to evaluate parts usage and lead time, and reviewed periodically to adjust minimum/maximum quantities and the Economic Order Quantity (EOQ). Economical order quantity may be considerd as the order quantity that will minimize the total inventory costs. Note the total ineventory costs consist of ordering costs and inventory carrying/holding costs. The real power of an inventory control system embedded in a CMMS is its ability to capture and analyze usage data both to apply EOQ and pay greater attention to an ABC classification. These applications in turn enable the company to optimize inventory cost.

"Shelf Life" Management and PM Plan for Stored Items

Components and sub-assemblies such as blowers, motor, motor-gearbox units, and bearings need to be appropriately lubricated for storage and may also require rotation of shafts to reduce damage to the bearings at specified intervals. It has been found that improper storage can damage the parts and reduce their life. Similarly, rubber and chemical materials, e.g., o-rings, oil seals, cylinder cups, and adhesives, have limited shelf life. All these type of materials should be identified in CMMS system with a PM or shelf-life management program.

Inventory Accuracy

Achieving a high level of inventory accuracy is a critical factor in the success of storeroom operations. Accurate inventory is defined as the actual quantity and types of parts in the right location in the storeroom matching exactly what is shown on the inventory system in the CMMS/EAM system. If a part, quantity, or location is not correct when matched against the system, then that location is counted as an error. Some limited variance can be tolerated in the case of certain supplies such as nuts and bolts, as they can be considered consumable items.

Inventory accuracy is important for several reasons. The consequences of inaccurate inventory are:

- If the part is not found in the location indicated in CMMS records, the repair can not be completed on time, thus delaying the asset availability for operations.
- An out-of-stock condition can occur because parts will not be ordered on time if the actual quantity is lower than the system record.
- If the system record number is lower than the actual inventory record, then the parts will be flagged for reorder by the system, even if not required, resulting in unnecessary inventory.
- Maintenance and operations personnel will lose confidence in the inventory system, CMMS, and in stores management. This situation can encourage proliferation of stock items to be stored in technician's tool boxes or floor cabinets.

Because inventory accuracy is very critical for the maintenance store, it is important that a process is established to ensure that high inventory accuracy of 95% or better is maintained. This means that 95% of the time, a part or material is found in the right location and that the quantity of them in the bin matches with the system inventory number.

Achieving a high level of inventory accuracy requires ensuring:

- All parts–material received against a purchased order should be recorded in an inventory system/CMMS.
- Additional information regarding parts — specific data such as manufacturer's number, serial number, lot size, cost, and shelf life —should be recorded in the system.
- All parts–materials issued to a work order should be recorded accurately along with the employee name, number, equipment, and projects.
- All parts–material not used after a repair or PM should be returned and recorded in the system and put back in right location.

A process should be set-up to perform cycle and location counts on a regular basis. This count can be daily, weekly, monthly, or yearly depending on the size of the store, value, and other factors such as current accuracy level. The store personnel can be assigned a number of bins/locations to be counted on a daily basis or a pre-assigned schedule to cover all items in the store in, for example, six months or one year. In some stores, specifically consumer warehouses, where large number of items such as books and CDs are kitted and shipped on an everyday basis, a weekend count by special part-time employees is performed to ensure inventory is accurate at the start of the week .

Parts Kitting Process

One of the functions of the storeroom is to provide parts, material, tools, and consumable supplies for the technicians to perform PM and repair tasks. The storeroom can build PM or repair part kits in advance of the scheduled PM tasks. The CMMS/EAM system should send a PM or repair schedule with a materials request to the storeroom in advance to hold parts inventory and to provide parts at right location on scheduled day.

The parts listed on the PM work order are picked from the storage locations and are placed into one of the kit bins. These kit bin locations are an extension of the storage locations, and the inventory control system in CMMS will track these kit locations with a staged status. When picking is completed, the entire cart is moved to a kit holding area, and scanned into the hold area location. The area maintenance supervisor or scheduler, or in some cases the technician, is informed of the kit status and its staged location. On PM or repair scheduled day, the technician picks

Figure 5.8 Kitting Bins.

up the kit and communicates with the inventory/CMMS system for any changes. In fact, in some organizations, the kit and other material are delivered on site, near the asset before the repair task is started. Figure 5.8 shows examples of kitting bins on mobile carts.

Total Inventory Costs

Operations and maintenance are the customers of an MRO store. Customers usually perceive quality service as the availability of goods, parts, materials, and tools when they want them. An MRO store must have sufficient inventory to provide high-quality customer service. On the other hand, high inventory levels require investments. Inventory costs consist of:

- Carrying cost: the cost of holding an item in the store
- Ordering cost: the cost of replenishing the inventory
- Stockout cost: loss of sales or production when an asset cannot be repaired and made available to produce due to a part stockout.

Economic Order Quantity (EOQ)

Economic order quantity (EOQ) analysis is one of the techniques which could be used to optimize inventory levels by ordering the “right” quantity at a specific time interval in order to minimize inventory cost but still meet customer needs.

EOQ helps optimize order quantity that will minimize the total inventory cost. EOQ is essentially an accounting formula that determines the point at which the combination of order costs and inventory carrying costs are the least. The result is the most cost effective quantity to order.

Although EOQ may not apply to every inventory situation, most organizations will find it beneficial in at least some aspect of their operation. Anytime we have repetitive purchasing of items such as bearings, filters, and motors, EOQ should be considered. EOQ is generally recommended in operations where demand is relatively steady. Still, items with demand variability such as seasonality can still use the model by going to shorter time periods for the EOQ calculation. We have to make sure that usage and carrying costs are based on the same time period.

To determine the most cost-effective quantities of an item, we will need to use the EOQ formula. The basic Economic Order Quantity (EOQ) formula is:

$$\text{EOQ} = \sqrt{\frac{2DS}{H}}$$

Where D – Demand/ Usage in units per year
S – Ordering cost per order
H – Inventory carrying cost per unit per year

The calculation itself is fairly simple. However, the task of determining the correct cost data inputs to accurately represent inventory and operations can be a bit of a project. Exaggerated order costs and carrying costs are common mistakes made in EOQ calculations.

Annual Demand

The number of units of an item used per year may be explained as the annual usage.

Ordering Cost

Also known as purchase cost, this is the sum of the fixed costs that are incurred each time an item is ordered. These costs are not associated with the quantity ordered, but primarily with physical activities required to process the order. There is a big variation in this cost. We have found that an order cost varying from $20–200 per order depending upon factors such as organization size. Usually order cost includes the cost to enter the purchase order or requisition, any approval steps, the cost to process the receipt, incoming inspection, invoice processing, and vendor payment. In some cases, a portion of the inbound freight may also be included in order

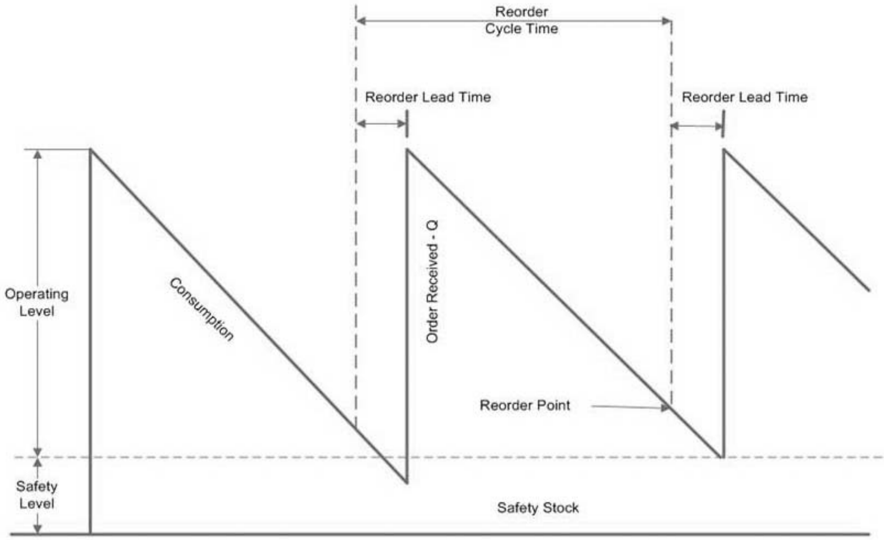

Figure 5.9 EOQ and stocking levels.

cost. These costs are associated with the *frequency* of the orders and not the *quantities* ordered.

Carrying Cost

Also called holding cost, carrying cost is the cost associated with having inventory on hand. It includes the cost of space to hold and service the items. Usually this cost varies between 20–30% of the item's value on an annual basis.

Figure 5.9 graphically portrays the concept of a typical EOQ and stocking levels. The illustration assumes a constant demand – consumption, failure rate, and constant lead time. In real practice, demands are not always constant and often reorder cycle changes with time.

The next two examples demonstrate how EOQ and total inventory costs may be computed.

Example #1

A plant buys lubricating oil in 55-gallon drums and its usage rate is an average of 132 drums of oil in a year. What would be an optimal order quantity and how many orders per year will be required? What would be the additional total cost of ordering and holding these drums in store if ordering cost is increased by $10/order? Plant data indicates that:

a) Preparing an order and receiving the material cost $60/order
b) The oil drum carrying (holding) cost is 22% per year. The average cost of a 55-gallon oil drum is $500.

$$\text{EOQ} = \sqrt{\frac{2DS}{H}}$$

Where,

Annual usage D = 132
Ordering cost S = $60
Annual carrying cost H = 22% of item cost = 0.22 x $500 = $110

$$\text{EOQ Q} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2 \times 132 \times 60}{110}} = 12 \text{ drums/order}$$

$$\text{Average number of oil drums on hand} = \frac{Q}{2} = 6 \text{ drums}$$

$$\text{Number of orders/year} = \frac{D}{Q} = \frac{132}{12} = \boldsymbol{11\ /\ year}$$

Total annual cost (TC) of ordering and holding oil drums in inventory

$$= \frac{Q}{2}H + \frac{D}{Q}S$$

$$= (12/2) \times 110 + (132/12) \times 60 = \$660 + \$660 = \$1320/\text{year}$$

Now, if the cost of ordering is increased by $10 to $70 per order, the new EOQ and total cost (TC) can be calculated as follows:

$$\text{EOQ (Q)} = \sqrt{\frac{2 \times 132 \times 70}{110}} = 13 \text{ drums/order}$$

$$\text{Number of orders/year (Q)} = \frac{D}{Q} = \frac{132}{13} = 10.15/\text{year} \sim 10/\text{year}$$

Total annual cost (TC) of ordering and holding oil drums;

$$\text{TC} = \frac{Q}{2}H + \frac{D}{Q}S$$

$$= \frac{13}{2}(110) + \frac{132}{13}(70) = \$715 + \$710 = \$1425/\text{year}$$

An increase of order cost by $10 has resulted in an increase of total cost by $105, from $1320/year to $1425/year.

Example #2

A plant maintenance department consumes an average of 10 pairs of safety gloves per day. The plant operates 300 days per year. The storage and handling cost is $3 per pair and it costs $25 to process an order.

a) What would be an optimal order quantity as well as the total cost of ordering and carrying this item?

b) If carrying cost increases by $0.50 per pair, what would be the new EOQ and total cost of carrying this item in store?

a) Given,

D = Annual demand = 10 x 300 = 3000 pairs

S = Ordering cost = $25/order

H = Carrying cost = $3/pair

$$\text{EOQ Q} = \sqrt{\frac{2DS}{H}}$$

$$\text{EOQ (Q)} = \sqrt{\frac{2 \times 3000 \times 25}{3}} = 224 \text{ pairs/order}$$

$$\text{Number of orders/year (Q)} = \frac{D}{Q} = \frac{3000}{224} = 13/\text{year}$$

Total annual cost of ordering and holding safety gloves (TC)

$$\text{TC}_{224} = \frac{Q}{2}H + \frac{D}{Q}S$$

$$= \frac{224}{2}(3) + \frac{3000}{224}(25) = \$336 + \$335 = \$671/\text{year}$$

If we change order quantity to 250/order, the new TC

$$\text{TC}_{250} = \frac{250}{2}(3) + \frac{3000}{250}(25) = \$375 + \$300 = \$675/\text{year}$$

If we change order quantity to 200/order, the new TC

$$\text{TC}_{200} = \frac{200}{2}(3) + \frac{3000}{200}(25) = \$300 + \$375 = \$675/\text{year}$$

An order quantity of 200 or 250 would give us the same total cost. Therefore, we could go with an EOQ of 200 gloves/order.

b) If the carrying cost is increased to $3.50/pair

D = Annual demand = 10 x 300 = 3000

S = Ordering cost = $25

H = Carrying cost = $3.50/pair

$$\text{EOQ (Q)} = \sqrt{\frac{2DS}{H}}$$

$$\text{EOQ (Q)} = \sqrt{\frac{2 \times 3000 \times 25}{3.5}} = 207 \text{ pairs/order}$$

$$\text{Number of orders/year (Q)} = \frac{D}{Q} = \frac{3000}{207} = 15/\text{year}$$

Total annual cost of ordering and holding safety gloves (TC)

$$TC_{207} = \frac{Q}{2}H + \frac{D}{Q}S$$

$$= \frac{207}{2}(3.5) + \frac{3000}{207}(25) = \$362 + \$362 = \$724/\text{year}$$

If we change order quantity to 200/order, the new TC

$$TC_{200} = \frac{200}{2}(3.5) + \frac{3000}{200}(25) = \$350 + \$375 = \$725/\text{year}$$

With increased carrying cost from \$3.00 to \$3.50 per glove, the new EOQ is still 200, but the total cost of ordering and carrying safety gloves would increase to \$725 per year.

New Technologies

New technology such as bar codes, Radio Frequency Identification Device (RFID), and handheld data collectors similar to those used in supermarkets or FedEx/UPS inventory systems could effectively help improve productivity of storeroom operations. The introduction of bar coding, auto ID (identification) systems, and now RFID technology into storerooms has resulted in a significant contribution to storeroom productivity, inventory accuracy, and error elimination. Use of this new technology in storerooms is a best practice.

Automated ID Technology

No discussion of parts storage would be complete without some discussion of automated ID technology. Although commonly used in distribution operations for years, the use of automated ID in MRO — tied mainly to CMMS use — is only now beginning to increase. Whereas a stand-alone maintenance system (particularly a smaller one) may function well with manual entry and tracking of parts, integration with manufacturing and distribution parts storage systems will almost certainly warrant the investment in and use of some form of automated ID technology. The discussion below covers the two most common automated ID technologies: bar coding and radio frequency identification (RFID).

Bar Code A barcode is an array of parallel bars and spaces arranged according to a particular symbology that allows automated scanning devices to read them. In use for almost three decades, bar codes are now familiar and commonplace in distribution and retail operations. However, only in recent years, maintenance organizations have begun aggressively implementing barcode system in MRO stores. When combined with a systematic storage process, the use of barcodes can virtually eliminate misidentified parts and the selection of incorrect parts, and greatly increase the efficiency of reusable parts and equipment tracking. Automated bar code tracking is a baseline enabler of systematic ID tracking and is a prerequisite for any effective MRO storage strategy. Organizations not currently using barcodes for MRO stores should investigate their use in the near future.

Overall benefits of a bar code solution include:

- More accurate and timely information
- Faster service
- Easier work for employees
- Lower labor costs
- Higher productivity than manual counting and recording
- More accurate inventory information

Many maintenance practices have been discussed in this chapter. Most of them are good or best practices depending upon where you are in your journey of maintenance excellence. All of them, when implemented and tailored to suit your environment, can provide better inventory control and service, and more efficient maintenance and purchasing activities. For example, when an organization redesigned its maintenance operations to capture all labor and material costs used on specific assets, it assigned a bar-coded metal tag to each piece of asset. This eliminated all labor and material charges against the wrong job and resulted in hundreds of hours saved because employees no longer had to fill out paperwork and key them into the system. This change also provided for 100 percent data capture. The organization used the information to develop a cost-effective preventive maintenance program.

Radio Frequency Identification (RFID) RFID is an automated identification and data collection technology that uses radio frequency waves to transfer data between a reader (interrogator) and items that have affixed tags (transponders). Unlike bar codes, which are familiar and well known to most people, RFID is still in limited use in industry, and even more so in maintenance operations. RFID is similar to bar coding in many aspects, as both use tags and labels affixed to the part for identification, and both use special readers to read the tag and/or label data. The major difference in the two is that RFID uses radio waves to read the tag data, whereas barcode readers use light waves (laser scanners).

Although still in early adoption, RFID offers several distinct advantages over traditional bar coding, including:

- No line of sight required
- Dynamic tag read/write capability
- Simultaneous reading and identification of multiple tags
- Tolerance of harsh environments

Many organizations have piloted RFID programs, and an increasing number are actively using RFID technology in MRO stores. Some areas of documented savings include:

- Reduced inventory control and provisioning costs
- Accurate configuration control and repair history
- Part installation and removal time tracking
- Accurate and efficient parts tracking
- Reduced parts receiving costs
- Elimination of data entry errors
- Improved parts traceability
- Reduced risk of unapproved parts

All maintenance organizations, even those currently without any system control, should investigate the use of RFID in both their MRO parts stores and directly on assets to replace so-called Brass Tag identification. The current rapid adoption of RFID in industry may soon allow it to overtake bar codes as the new industry standard for automatic parts or assets identification.

5.5 Performance Measures and Indicators

There are several measures and performance indicators that indicate the efficiency of storeroom operations. Some key indicators are:

- Percentage of inactive inventory
- Number of inactive parts (SKUs) in the past year / total number of parts (SKUs)
- Percentage of ABC classification — this year to past years
- Inventory accuracy in percent
- Number of errors found / total bin locations
- Percentage inventory cost to plant value
- Parts inventory value / total plant replacement value
- Inventory growth rate in number of parts and suppliers
- Percentage of stock-outs as compared to past years
- Number of stock outs / total parts issued
- Inventory turnover ratio

5.6 Summary

Continually changing business pressures are forcing maintenance departments to review their operational processes and find ways to run leaner, faster, and more efficiently than ever before. Unless MRO stores are integrated with purchasing, operations, and material planning, any optimization of maintenance strategy will be suboptimal, often resulting in reduction of overall organization efficiency. Managing inventory / material and parts storage effectively is a key strategy that can't be overlooked. Efficient storage principles, such as storing pre-kitted parts and storing parts close to the point of use, can greatly improve maintenance store performance. The parts storage equipment that best fits with the overall storage strategy of the organization can then be selected to meet maintenance and operations need. The sharing of storage equipment often results in the ability to justify storage automation, which can lead to efficiency gains not only in maintenance, but also across the organization.

Almost all scheduled maintenance requires specified materials and parts to accomplish the task. Advance planning for maintenance processes and pre-kitting of the parts can greatly increase the efficiency of maintenance and reduce the wait time for maintenance personnel.

Parts held in inventory needed solely in the event of an unscheduled asset failure are critical spares. Planned maintenance activities use service parts on a regular schedule. The part usage is fundamentally different between the two categories, and so the storage strategy of each should vary as well. A major aspect of spares storage is balancing availability against the cost of storage. Tracking the usage of all parts by user, task, location, etc., allows reporting and analyzing of specific usage patterns. Particularly with consumables, the very act of tracking usage will cause awareness, and overall usage will decrease.

Tools such as ABC analysis and EOQ should be used to optimize inventory. The benefits of optimizing materials and spares inventory include reduction in inventory costs, elimination or reduction of craft waiting time, and reduction in stock returns. The decision of what spares to stock should not be based on vendors' recommendations, but instead on FMEA/RCM analysis, the stocking costs, the lead time to procure, and impact on operations if spares are not in stock.

Holding all critical parts in inventory can result in very high MRO storage expenses. Consider partnering with local industry and vendors for sharing some critical spares. Eliminating idle inventory is possible by negotiating delivery controls and establishing vendor trust.

Focus on implementing the following best practices to improve MRO store effectiveness:

- Create a culture to emphasize that the storeroom is a service provider and its objective is to provide the right parts–material at the right location at the right time.
- Ensure inventory accuracy.
- Perform daily/weekly cycle counting as a part of routine store room operations.
- Use auto ID to streamline data entry and reduce errors.
- Build PM / repair kits in advance.
- Establish shelf life and PM program for stored items.
- Ensure all parts–material get charged to proper asset.
- Establish KPI to measure and track performance.

5.7 References and Suggested Reading

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Chapter 6

Measuring and Designing for Reliability and Maintainability

Insanity is doing the same thing over and over again and expecting different results.
-- Albert Einstein

After reading the chapter, the reader will be able to:

- Understand reliability and why it is important
- Calculate reliability, availability, and maintainability
- Measure and specify reliability
- Review design for reliability
- Explain the impact of O&M costs on an asset's life cycle cost

6.1 Introduction

Asset reliability is an important focal point for many organizations. It's a source of competitive advantage for many visionary companies. It is the central theme for maintenance departments trying to improve their bottom-line. To some, reliability identifies the right work, and is synonymous with reliability centered maintenance (RCM). Reliability is not just RCM, however; it has a much broader meaning. Understanding the term reliability and how it differs from maintenance is key to establishing a successful program for improving reliability in any organization. In this chapter, we will define key terms related to reliability and discuss important factors that will help realize higher reliability of assets and plants.

Key Terms and Definitions

Availability (A)

The probability that an asset is capable of performing its intended function satisfactorily, when needed, in a stated environment. Availability is a function of reliability and maintainability.

Failure

The loss of an asset's ability to perform its required function. It does not require the asset to be inoperable. The failure could also mean reduced speed, or not meeting operational or quality requirements.

Failure Rate (FR)

The number of failures of an asset over a period of time (per unit measurement of life). Failure rate is considered constant over the useful life of an asset. It's normally expressed as the number of failures per unit time and is the inverse of Mean Time Between Failure (MTBF). FR is denoted by Lambda (Ï).

Mean Time Between Failures (MTBF)

This is a basic measure of asset reliability. It is calculated by dividing total operating time of the asset by the number of failures over some period of time. MTBF is the inverse of failure rate (FR).

Mean Time to Repair (MTTR)

This is the average time needed to restore an asset to its full operational condition upon a failure. MTTR is the time to repair the asset and is an important measure of maintainability.

Maintainability (M)

This represents the ease and speed of repair and maintenance actions with which an asset can be restored to operating condition, following a failure. It is measured by MTTR.

Reliability (R)

This is the probability that a system will perform its intended function satisfactorily for a specified period of time under stated conditions. It is usually expressed as a percentage and measured by the mean time between failures (MTBF).

Reliability Centered Maintenance (RCM)

A systematic and structured process to develop an efficient and effective maintenance plan for an asset to minimize the probability of failures. The process insures safety and mission compliance.

Uptime

Uptime is the time during which an asset or system is either fully operational or is ready to perform its intended function. It's the opposite of downtime.

What and Why Reliability?

Reliability is a broad term that focuses on the ability of an asset to perform its intended function to support manufacturing or to provide a service. Many books written about reliability tend to focus on Reliability Centered Maintenance (RCM). Reliability is not just RCM. RCM is a proactive methodology utilizing reliability principles for identifying the right work to be done to maintain an asset in a desired condition so that it can keep performing its intended function. In fact, RCM is basically a PM optimizing tool to define the "right" maintenance actions. In its most effective and widely-accepted form, it consists of seven structured steps for building a maintenance program for a specific asset. When organizations first try to improve reliability, they label this undertaking as RCM, but RCM really differs from a reliability improvement initiative. Details of the RCM process will be discussed in chapter 8.

Improving asset reliability is important to the success of any organization, particularly to its operation and maintenance activities. To do this, we need to understand both reliability and maintenance, and how they're interrelated. Reliability is the ability of an asset to perform a required function under a stated set of conditions for a stated period of time, called mission time. Three key elements of asset reliability are the asset function, the conditions under which the asset operates, and mission time. The term *reliable assets* means that the equipment and plant are available as and when needed, and they will perform their intended function over a predetermined period without failure. Reliability is a design attribute and should be "designed in" when an asset is designed and built.

On the other hand, maintenance is an act of maintaining, or the work of keeping an asset in proper operating condition. It may consist of performing maintenance inspection and repair to keep assets operating in a safe manner to produce or provide designed capabilities. These actions can be preventive maintenance (PM) and corrective maintenance (CM) actions. So, maintenance keeps assets in an acceptable working condition, prevents them from failing, and, if they fail, brings them back to their operational level effectively and as quickly as possible.

Maintainability is another term we need to understand with reliability. It is another design attribute which goes hand in hand with reliability. It reflects the ease of maintenance. The objective of maintainability is to insure maintenance tasks can be performed easily, safely, and effectively. Reliability and maintainability attributes are usually designed into the asset to minimize maintenance needs by using reliable components, simpler replacement, and easier inspections.

With these definitions, the differences start to become clear. Reliability is designed in and is a strategic task. Maintenance keeps assets functioning and is a tactical task. Maintenance does not improve reliability, it just sustains it. Improving reliability requires redesign or replacement with better and reliable components. Improving reliability needs a new thinking — a new paradigm. Rather than asking how to restore the capability of a failed asset efficiently and effectively, we need to ask what we can do proactively to guarantee that the asset does not fail within the context of meeting the business needs of the overall operation.

A challenge in this transition is the belief that we should strive to maximize asset reliability. However, it has been found that insuring 100% reliability — although a great goal —often results in high acquisition costs and may require a high level of maintenance to sustain high reliability. It may not be a cost-effective strategy; it also may not be affordable. We need to define an asset's or plant's reliability requirements in the context of supporting the underlying business needs. Then, we inevitably realize that we may need a different reliability and an affordable maintenance program.

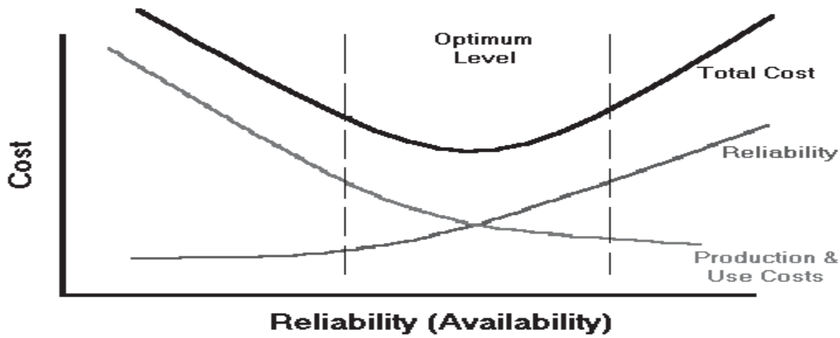


Figure 6.1 Reliability/ Availability Economics

As shown in Figure 6-1, Reliability / Availability Economics, we need to find the right level of reliability required to give us the optimum total cost. This graph illustrates the production or use cost, which is operations and downtime time cost verses the reliability (and maintenance) cost.

Why is Reliability Important?

Asset reliability is an important attribute for several reasons, including:

- **Customer Satisfaction.** Reliable assets will perform to meet the customer's needs on time and every time. An unreliable asset will negatively affect the customer's satisfaction severely. Thus high reliability is a mandatory requirement for customer satisfaction.
- **Reputation.** An organization's reputation is very closely related to the reliability of their services. The more reliable plant assets are, the more likely the organization is to have a favorable reputation.
- **O & M Costs.** Poor asset performance will cost more to operate and maintain.
- **Repeat Business.** Reliable assets and plant will insure that customer's needs are being met in a timely manner. Customer satisfaction will bring repeat business and also have a positive impact on future business.
- **Competitive Advantage.** Many leading and visionary companies have began achieving high reliability / availability of their plants

and assets. As a result of their greater emphasis on plant reliability improvement programs, they gain an advantage over their competition.

Reliability vs. Quality Control

In a manufacturing process, quality control (QC) is concerned with how the process is meeting specifications to guarantee consistent product quality. Its objective is to see that both an asset and its components are manufactured and assembled with high quality standards and meet the designed specifications. Thus, QC is a snapshot of the manufacturing process' quality program at a specific time. Reliability is usually concerned with failures after an asset has been put in operation for its whole life. The QC of manufacturing processes for building of the asset makes an essential contribution to the reliability of an assets — it can be considered as an integral part of an overall reliability program.

The same way that a chain is only as strong as its weakest link, an asset is only as good as the inherent reliability of the asset, and the quality of the manufacturing process used to build or assemble this asset. Even though an asset may have a reliable design, its reliability may still be unsatisfactory when the asset is built and installed or used in the field. The reason for this low reliability may be that the asset or its components were poorly built. This could be result of a substandard manufacturing process to build the asset. For example, cold solder joints could pass initial testing at the manufacturer, but fail in the field as the result of thermal cycling or vibration. This type of failure does not occur due to poor design, but as a result of an inferior manufacturing process.

Usually assets are designed with a level of reliability based on the effective use of reliable components and their configurations. Some components may be working in series and others in parallel arrangements to provide the desired overall reliability. This level of reliability is called inherent reliability. After the asset has been installed, the reliability of an asset can not be changed without redesigning or replacing it with better and improved components. However, asset availability can be improved by repairing or replacing bad components before they fail, and by implementing a good reliability-based PM plan.

Evaluating and finding ways to attain high asset reliability are key aspects of reliability engineering. There are a number of practices we can apply to improve the reliability of assets. We will be discussing these practices to improve reliability later in this chapter, as well as in other chapters.

6.2 Defining and Measuring Reliability and Other Terms

There are two types of assets: repairable and non-repairable.

Assets or components that can be repaired when they fail are called repairable, e.g., compressors, hydraulic systems, pumps, motors, and valves. Reliability of these repairable systems is characterized by the term MTBF (Mean Time Between Failure).

Assets or components that can't be repaired when they fail are called non-repairable, e.g., bulbs, rocket motors, and circuit boards. Some components such as integrated circuit boards could be repaired, but the repair work will cost more than replacement cost of a new component. Therefore, they're considered non-repairable. Reliability of non-repairable systems is characterized by the term MTTF (Mean Time to Failure).

Reliability, Maintainability and Availability

Reliability (R), as defined in military standard *(MIL-STD-721C),* is "the probability that an item will perform its intended function for a specific interval under stated conditions."

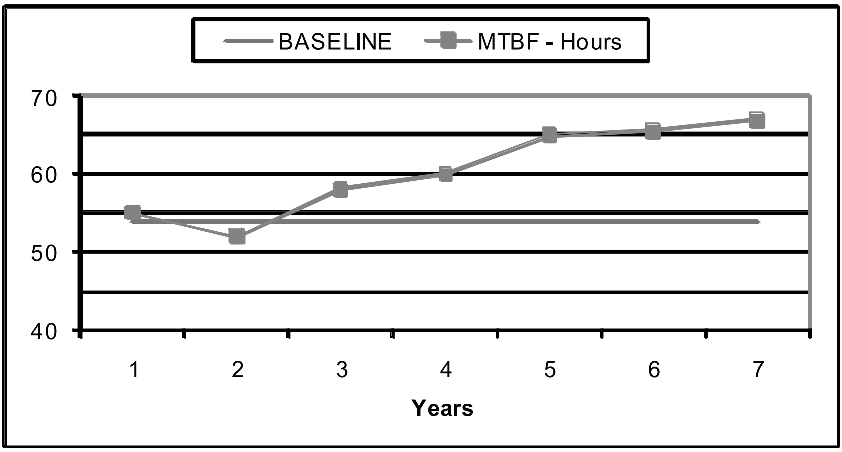
As defined here, an item or asset could be an electronic or mechanical hardware product, software, or a manufacturing process. The reliability is usually measured by MTBF and calculated by dividing operating time with number of failures. Suppose an asset was in operation for 2000 hours (or for 12 months) and during this period there were 10 failures. The MTBF for this asset is:

MTBF = 2000 hours / 10 failures = 200 hours per failure,
or
12 months / 10 failures = 1.2 months per failure

A larger MTBF generally indicates more reliable asset or components.

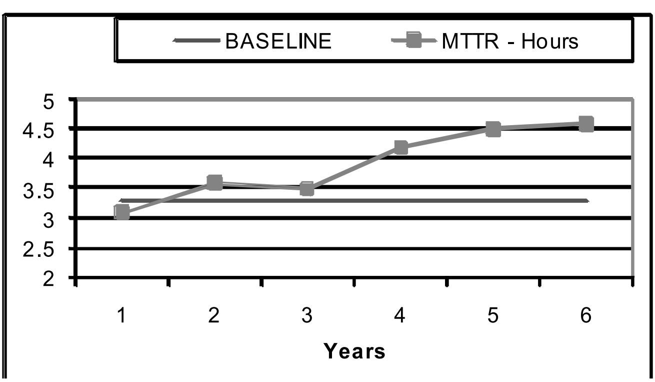
Maintainability (M), is the measure of an item's or asset's ability to be retained in or restored to a specified condition when maintenance is performed by personnel having specified skill levels, using prescribed procedures and resources at each stage of maintenance and repair. Maintainability is usually expressed in hours by Mean Time to Repair (MTTR), or sometimes by Mean Downtime (MDT). MTTR is the average time to repair assets. It is pure repair time (called by some *wrench time*). In contrast, MDT is the total time the asset is down, which includes repair time plus additional waiting delays.

In simple terms, maintainability usually refers to those features of assets, components, or total systems that contribute to the *ease* of maintenance and repair. A lower MTTR generally indicates easier maintenance and repair.



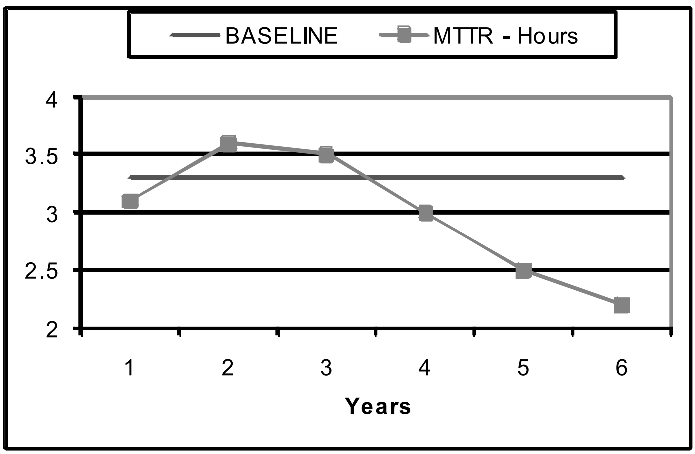
Figures 6.2 a

Figures 6-2 a, b, and c show trends of MTBF and MTTR data in hours. The base line should be based on at least one-to-three years of data. This type of trend line is essential for tracking impact of improvements. Figure 6.2a shows MTBF trend data, which is increasing. This trend is a good one.



Figures 6.2 b

Figure 6-2b shows MTTR trend data, which is increasing. It is going in the wrong direction. We need to evaluate why MTTR is increasing by asking: Do we have the right set of skills in our work force? Do we identify and provide the right materials, tools, and work instructions? What can we do to reverse the trend?



Figures 6.2 c

Figure 6-2c shows MTTR trend data, which is decreasing. In this case, the trending is in the right direction. To continue this trend, we need to ask the questions: What caused this to happen? What changes did we make? Trending of this type of data can help to improve the decision process.

Availability

Availability (A) is a function of reliability and maintainability of the asset. It's measured by the degree to which an item or asset is in an operable and committable state at the start of the mission when the mission is called at an unspecified (random) time.

In simple terms, the availability may be stated as the probability that an asset will be in operating condition when needed. Mathematically, the availability is defined:

$$\text{Availability (A)} = \frac{MTBF}{MTBF + MTTR} = \frac{Uptime}{Uptime + Downtime}$$

The availability defined above is usually referred as inherent availability (A_i). It is the designer's best possible option.

In reality, actual availability will be lower than inherent availability as the asset will be down due to preventive and corrective maintenance actions. Another term, Operational Availability (A_o), considers both preventive and corrective maintenance and includes all delays — administrative, materials and tools, travel, information gathering, etc. — that keep the asset unavailable. Achieved Availability (A_a) includes preventive maintenance, but not delays for getting materials and tools, information, etc.

Naturally, the designer or the manufacturer of the asset should be responsible for inherent or achieved availability. The user of the asset should be interested in operational reliability. The inherent availability will be degraded as we use the asset and it can never be improved upon without changes to the hardware and software. Availability can be improved by increasing reliability and maintainability. The trade-off studies should be performed to evaluate cost effectiveness of increasing MTBF (reliability) or decreasing MTTR (maintainability). For the sake of simplicity and to reduce confusion, we will be using the term *Availability* in this book to represent inherent availability.

The standard for availability is about 95%, meaning that the asset is available for 9.5 hours out of 10. This is based on general industry expectations. In some cases, if assets are not very critical, the standard may be lower. But in case of critical assets such as aero-engines or assets involved with 24-7 operations, the standard may require 99% or higher availability.

In general, the cost to achieve availability above 95% increases exponentially. Therefore, we need to perform operational analysis to justify high availability requirements, particularly if it's over 97 percent.

The Bathtub Curve and Reliability Distribution

The bathtub curve seen in Figure 6-3 is widely used in reliability engineering, although the general concept is also applicable to people as well. The curve describes a particular form of the hazard function which comprises three parts:

- The first part is a decreasing failure rate, known as early failures or infant mortality. It's similar to our childhood.
- The second part is a constant failure rate, known as random failures. It's similar to our adult life.
- The third part is an increasing failure rate, known as wear-out failures. It's similar to our old age.

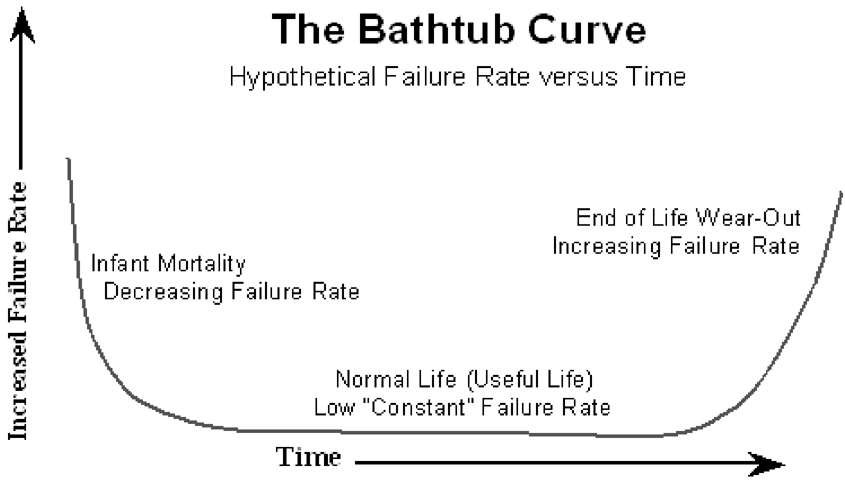


Figure 6.3

The bathtub curve is generated by mapping the rate of early infant mortality failures when first introduced, the rate of low random failures with constant failure rate during its useful life, and finally the rate of wear out failures as the asset approaches its design lifetime.

In less technical terms, in the early life of an asset adhering to the bathtub curve, the failure rate is high. However, it quickly decreases as defective components are identified and discarded, and early sources of potential failure, including installation errors, are eliminated. In the mid-life of an asset, the failure rate is generally low and constant. In the late life of the asset, the failure rate increases, as age and wear take its toll.

The airline industry and the U.S. Navy performed studies in the 1960s and 1970s to have a better understanding of asset failures. These studies showed that although all types of assets don't follow the bathtub curve failure concept exactly, they still remain fairly close. All assets followed a constant or slightly increasing failure rate for most of their life. Some didn't follow early mortality rate and some didn't have a wear out region either. Figure 6-4 shows a series of these failure patterns based on original study data. The failure patterns are categorized in two groups — age related and random. Fewer than 20% of failures follow an age degradation pattern; the remaining follow a random pattern with constant failure rate.

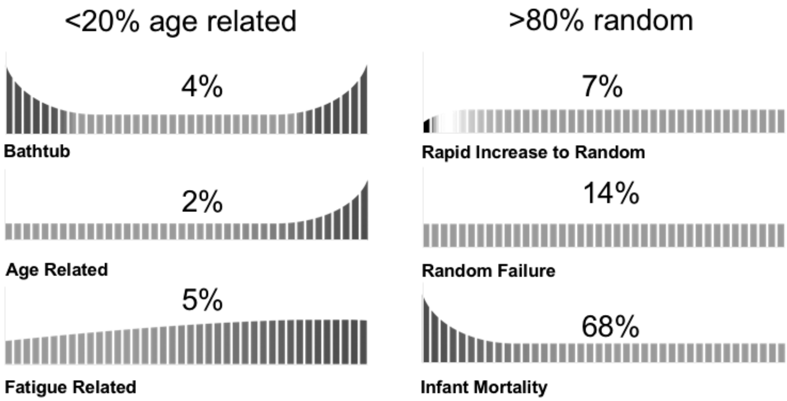


Figure 6.4 Failure Patterns

Reliability Failure Distribution

The exponential distribution is one of the most common distributions used to describe the reliability of an asset or a component in a system. It models an asset or component with the constant failure rate, or the flat section of the bathtub curve. Most of the assets, consumer or industrial, follow the constant failure rate for their useful life, so exponential distribution is widely used to estimate the reliability. The basic equation for estimating reliability, $R_{(t)}$, is

$$R_{(t)} = e^{-\lambda t}$$

where

λ (lambda) = Failure rate = 1/MTBF
t = mission time, in cycles, hours, miles, etc.
(Note: e is base of the natural logarithm = 2.71828)

Calculating Reliability and Availability

Example 1

A hydraulic system, which supports a machining center, has operated 3600 hours in the last two years. The plant's CMMS system indicated that there were 12 failures during this period. What is the reliability of this hydraulic system if it is required to operate for 20 hours or for 100 hours?

MTBF = operating time / # of failures = 3600 / 12 = 300 hours
Failure rate = 1 / MTBF = 1/ 300 = 0.003334 / hour

Reliability for 20 hours of operations,

$R_{(t)} = e^{(-\lambda t)}$

$R_{(20)} = e^{-(20)(0.003334)} = 93.54\%$

Reliability for 100 hours of operations,

$R_{(100)} = e^{-(100)(0.003334)} = 71.65\%$

For 100 hours of operation, the reliability of hydraulic system is 71.65%. This means that there is a 71.65% probability that the hydraulic system will operate without any failure. If we need to operate the system for only 20 hours, however, the probability of failure-free operations will increase to 93.54%.

Now, let us suppose that there is a need to operate this hydraulic system for 100 hours to meet a key customer's needs and the current reliability of 71.65% is not acceptable. The system needs to have 95% or better assurance (probability) to meet the customer's need.

To have reliability requirements of 95% for 100 hours of mission time, we need to calculate a new failure rate, λ. We use the reliability equation,

Required Reliability = 0.95 = $R_{(100)} = e^{(-\lambda \text{ x } 100)}$

Solving this equation, gives us

$(\lambda \text{ x } 100) = 0.05$

$100\ \lambda = 0.05$

Thus,

Failure rate λ = 0.0005 or MTBF = 2000 hours

This indicates that the failure rate needs to be dropped from 0.00334 (or an MTBF of 300 hours) to a new failure rate of 0.0005 (or an MTBF of 2000 hours). If we consider the same 3600 operating hours, then the number of failures needs to be reduced from 12 to 1.8. A Failure / FMEA analysis need to be performed on this hydraulic system to identify unreliable components. Some components may need to be redesigned or

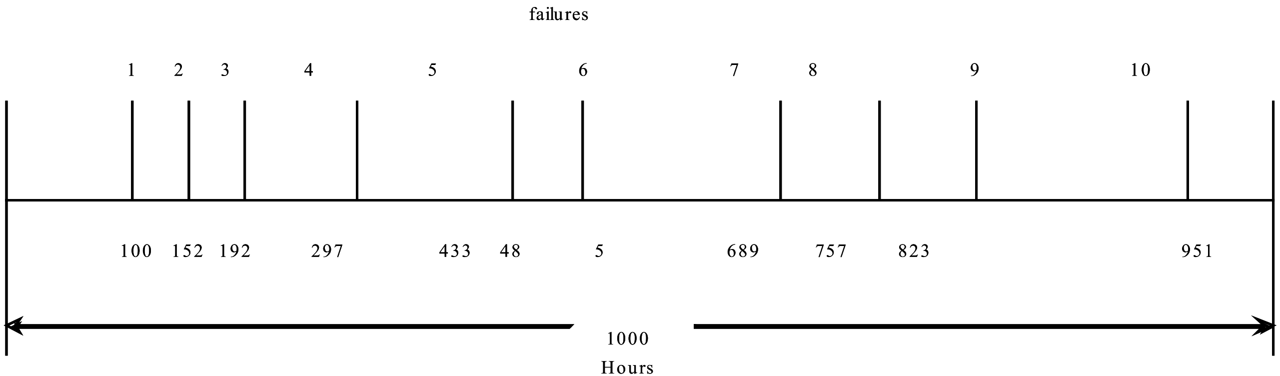


Figure 6.5

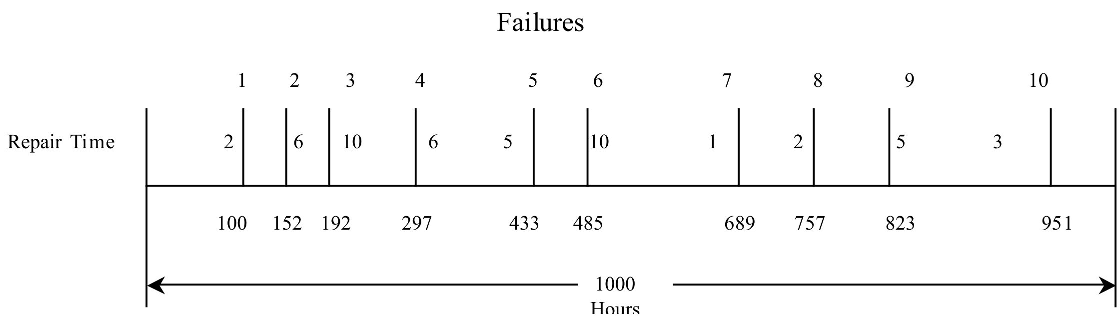


Figure 6.6

replaced to achieve the new MTBF of 2000 hours.

Example 2

A plant's air compressor system operated for 1000 hours last year. The plant's CMMS system provided the following data on this system:

Operating time = 1000 hours

Number of failures, random = 10

Total hours of repair time = 50 hours

What's the availability and reliability of this compressor system if we have to operate this unit for 10, 20, or 100 hours? Figure 6.5 shows the failure data and Figure 6.6 shows repair time data for those failures.

Figure 6-5 shows that the first failure happened at 100 hours of operation, the second at 152 hours of operation, and so forth. Figure 6-6 shows that the first failure happened at 100 hours of operation and took 2 hours to repair; the second failure happened at 152 hours of operation and took 6 hours to repair; and so forth. The total repair time for 10 failures is 50 hours.

Calculating MTBF and Failure Rate

$$\text{MTBF} = \frac{\textit{Operating Time}}{\textit{\# of Failures}} = \frac{\textit{1000 hours}}{\textit{10 Failures}} = 100 \text{ hours}$$

This indicates that the average time between failures is 100 hours.

$$\text{Failure Rate } (\lambda \text{ - Lambda}) = \frac{1}{MTBF} = \frac{1}{100} = 0.01 \text{ Failures /Hour}$$

Calculating MTTR and Repair Rate

$$\text{MTTR} = \frac{\textit{Total Repair Time}}{\textit{\# of Failures}} = \frac{\textit{50 hours}}{\textit{10 Failures}} = 5 \text{ hours}$$

$$\text{Repair Rate } (\mu) = \frac{1}{MTTR} = \frac{1}{5} = 0.2$$

Calculating Availability

Earlier, we calculated,

Mean Time Between Failures (MTFB) = 100 hours

Mean Time To Repair (MTTR) = 5 hours, and

Then,

$$\text{Availability (A)} = \frac{MTBF}{MTBF + MTTR} = \frac{Uptime}{Uptime + Downtime}$$

$$\text{Availability} = \frac{MTBF}{MTBF + MTTR} = \frac{100}{100 + 5} = 0.95 = 95\%$$

or

$$\frac{Uptime}{Uptime + Downtime} = \frac{1000 - 50 = 950}{950 + 50} = 0.95 = 95\%$$

This means that the asset is available 95% of the time and is down for 5% of the time for repair.

Calculating Reliability

As calculated earlier for the compressor unit,

MTBF = 100 hours

$$\text{Failure Rate } \lambda \text{ (FR)} = \frac{1}{MTBF} = \frac{1}{100} = 0.01 \text{ Failures /Hour}$$

$$\text{Reliability } R_{(t)} = e^{-\lambda t}$$

If t = time = 10 hours and $\lambda = 0.01$, then

$$\text{Reliability } (R_{10}) = e^{-\lambda t} = e^{-(.01)(10)} = e^{-(.1)} = 0.90 \text{ or } 90\%$$

If t = 20 hours and $\lambda = 0.01$, then

$$\text{Reliability } (R_{20}) = e^{-\lambda t} = e^{-(.01)(20)} = e^{-(0.2)}$$
$$= 0.818 \text{ or } 81.8\%$$

If t = time = 100 hours and $\lambda = 0.01$, then

$$\text{Reliability } (R_{100}) = e^{-\lambda t} = e^{-(.01)(100)} = e^{-(1)}$$
$$= 0.3678 \text{ or } 36.78\%$$

So, for this compressor system with MTBF of 100 hours,
Reliability for 10 hours of operation = 90%
Reliability for 20 hours of operation = 82%
Reliability for 100 hours of operation = 37%

This data indicates that reliability of the air compressor unit in this example is 90% for 10 hours of operation. However, reliability drops to 37% if we decide to operate the unit for 100 hours. For 20 hours of operation, reliability is 82%. If this level of reliability is not acceptable, then we need to perform failure /FMEA analysis to determine what component needs to be redesigned or changed to reduce the number of failures, thereby increasing reliability.

Reliability Block Diagram (RBD)

The failure logic of an asset, components, or a group of assets and components called a system can be shown as a reliability block diagram (RBD). This diagram shows logical connections among the system's components and assets. The RBD is not necessarily the same as a schematic diagram of the system's functional layout. The system is usually made of several components and assets which may be in series, parallel, or combination configurations to provide us the designed (inherent) reliability. The RBD analysis consists of reducing the system to simple series and parallel component and asset blocks which can be analyzed using the mathematical formulas.

Figure 6-7 shows a simple diagram, using two independent components and assets to form a system in series.

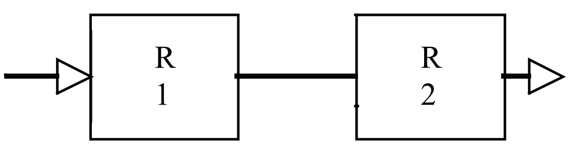


Figure 6.7

The reliability of a system with multiple components in series is calculated by multiplying individual reliability of each component,

$$R_{sys} = R_1 \times R_2 \times R_3 \times R_4 \times \ldots R_n ,$$

And the reliability of system R_{sys12} as shown in Figure 6.6

$$R_{sys\ 12} = R_1 \times R_2$$

or

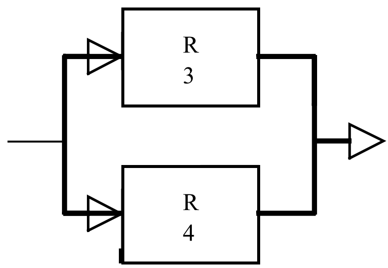
$$R_{sys\ 12} = e^{-(\lambda 1 + \lambda 2)t}$$

Where λ is failure rate and t is the mission time.

Active Redundancy or Parallel System

The RBD for the simplest redundant system is shown in Figure 6-8. This system is composed of two independent components and assets with reliability of R_3 and R_4

Figure 6.8



The reliability of a parallel system as shown is often written as,

$$R_{sys34} = 1 - (1 - R_3)(1 - R_4)$$

or

$$R_{sys34} = R_3 + R_4 - (R_3 \times R_4)$$

or

$$R_{sys34} = e^{-(\lambda 3)t} + e^{-(\lambda 4)t} - e^{-(\lambda 3 + \lambda 4)t}$$

In this arrangement, the reliability of the system, R_{sys34}, is equal to the probability of component 3 or 4 surviving. It simply means that one of the components is needed to operate the system and the other component is in active state and available if the first one fails. Therefore, the reliability of the whole system in parallel configuration is much higher than in series configuration. The components in parallel improve system reliability whereas components in series lower system reliability.

Standby redundancy is achieved when, in a redundant system, the spare component is not in an active mode continuously but gets switched on only when the primary component fails. In standby mode, the resultant reliability is a little higher in comparison to active mode. However, the assumption is made that switching is done without failure or without any delay. The reliability of two component system in standby mode is:

$$R_{sys\text{-}standby} = e^{-(\lambda)t} + \lambda\, t\, e^{-(\lambda)t}$$

Example 3

In a two-component parallel system with a failure rate of 0.1 /hour of each component, what would be the active and standby reliability of the system for one hour of operation?

In this example, $\lambda_3 = \lambda_4 = 0.1$ and t = 1 hour, then active reliability

$$R_{active} = e^{-(\lambda 3)t} + e^{-(\lambda 4)t} - e^{-(\lambda 3 + Ï4)t}$$

or

$$= R_3 + R_4 - (R_3 R_4)$$

$$(\text{as } R_3 = R_4 = e^{-(\lambda 3)t} = e^{-(0.1)1} = 0.09048)$$

$$= 0.9048 + 0.9048 - 0.81867 = 0.9909$$

$$R_{\text{-}standby} = e^{-(\lambda)t} + \lambda\, t\, e^{-(\lambda)t} \text{ or } = R + \lambda\, t\, R$$

$$= 0.9048 + (0.1 \times 1 \times 0.9048) = 0.99528$$

m – out – of – n Reliability Models

In real application, there will be many components and assets in series and parallel arrangements, depending upon design requirements. For example, Figure 6-9 shows a typical system comprised of 13 components, or individual assets, arranged in a combination of series and parallel configuration. The system reliability can be determined by first calculating individual component and asset reliability, then consider the system's subsystems and, finally the system as a whole. Reliability of some of the subsystems that are in parallel arrangements can be calculated using *m-out-of-n* reliability formulas. This mean how many m legs (components in series) are necessary out of n legs for the system to operate properly. In Figure 6-9, subsystem B has three legs, but we need only one to operate the system. Similarly subsystem C has three components and assets in parallel, and we need two to operate.

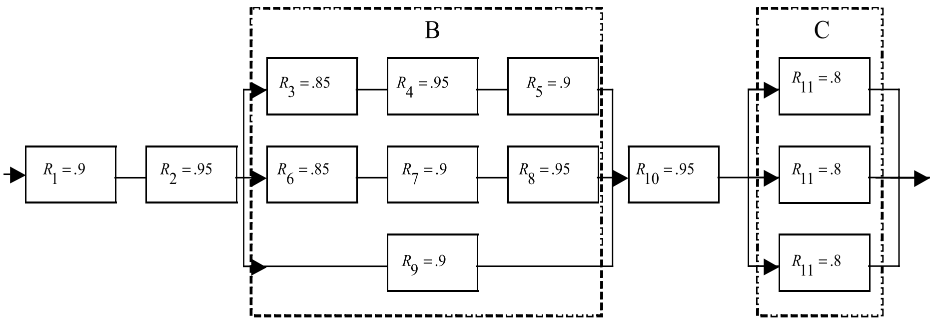


Figure 6.9

A simple approach for calculating the reliability of m-out-of-n systems is utilizing the binomial distribution and the relationship $(R + Q)^n = 1$, where R is reliability, Q is unreliability, and n is the number of elements. Figure 6-10 shows the formula for 2-, 3-, and 4-element systems to calculate system reliability.

The reliability of the system as shown in Figure 6-9,

$$R_{sys} = R_1 \text{ x } R_2 \text{ x } R_B \text{ x } R_{10} \text{ x } R_C$$

m - # of Working Element	**Overall System Reliability**
1 out of 2 2 out of 2	$R^2 + 2R(1 – R) = 1 – (1 – R)^2$ R^2
1 out of 2 2 out of 3 3 out of 3	$R^3 + 3R^2(1 – R) + 3R(1 – R)^2 = 1 – (1 -$ $R^3 + 3R^2(1 – R)$ R^3
1 out of 4 2 out of 4 3 out of 4 4 out of 4	$R^4 + 4R^3(1 – R) + 6R^2(1 – R)^2 + 4R(1$ $= 1 - (1 – R)^4$ $R^4 + 4R^3(1 – R) + 6R^2(1 – R)^2$ $R^4 + 4R^3(1 – R)$ R^4

Assumption: Each element's or component's reliabil
same = R

Figure 6.10 m-out -of-n Reliability Models

R_B is an active parallel configuration which is equal to

$$R_B = 1 - [1 - (R_3 \text{ x } R_4 \text{ x } R_5)]\ [1 - (R_6 \text{ x } R_7 \text{ x } R_8)]\ (1 - R_9)$$
$$= 1 - [1 - (0.85 \text{ x } 0.95 \text{ x } 0.9)]\ [1 - (0.85 \text{ x } 0.9 \text{ x } 0.95)]\ (1 - 0.9)$$
$$= 1 - (1 - 0.7267)\ (1 - 0.7267)\ (0.1)$$
$$= 1 - 0.00746$$
$$= 0.9925$$

R_c is another active parallel configuration, but it requires 2 (m)-out-of-3(n) to operate. Here the reliability is equal to:

$$R = 1 \sum^{m-1} - \binom{n}{i} R^i (1 - R)^{n-i}$$

$$R_c = 1 - \frac{3x2}{3x2} \quad R^0_{11} (1 - R_{11})^3 - R_{11} (1 - R_{11})^2$$
$$= 1 - (0.2)^3 - [3 \text{ x } 0.8\ (0.2)^2]$$
$$= 1 - 0.008 - 0.096$$
$$= 0.896$$

We could also use the binomial distribution, from Figure 6-10 to calculate R_c

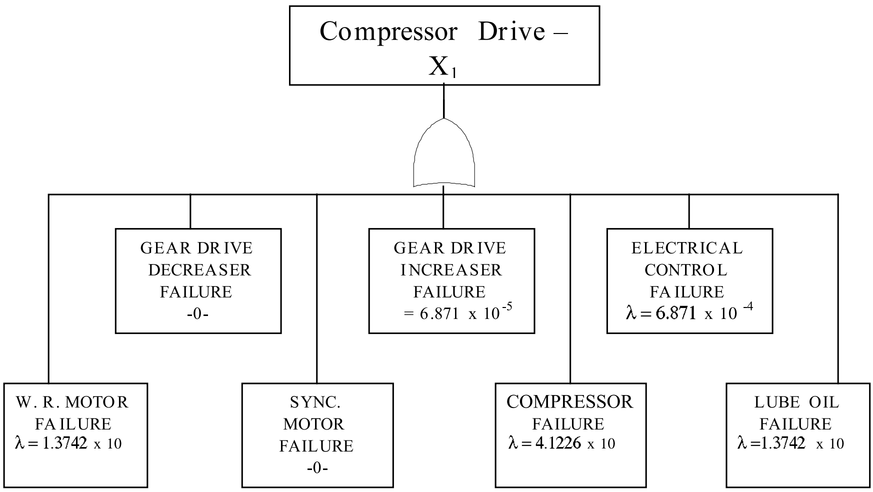
$$R_c = R^3 + 3R^2 (1 - R)$$
$$= (0.8)^3 + 3\ (0.8)^2\ (1 - 0.8)$$
$$= 0.896$$

The whole system reliability

$$R_{sys} = 0.9 \text{ x } 0.9 \text{ x } 0.9925 \text{ x } 0.95 \text{ x } 0.896$$
$$= 0.6843$$

Example 4

Figure 6-11 shows a compressor drive system consisting of seven components, motors, gear boxes, the compressor itself, electrical controls, and lube oil system, with failure rates based on four years of data. All components are assumed to be in series arrangement. Figure 6-12 shows the same compressor system in RBD format.



Figures 6.11

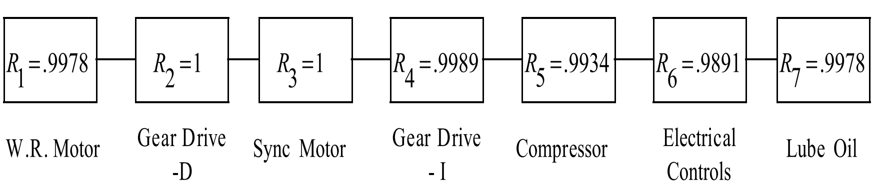
The total system failure rate based on the last 4 years of data,

$$\lambda_{X_1} = 1.3742x10^{-4} + 0 + 0 + 6.871x10^{-5} + 4.1226x10^{-4} + 6.871x10^{-4} + 1.3742x10^{-4}$$
$$= 1.443 \text{ x } 10^{-3} = 0.001443$$

Therefore, MTBF of total system-

$= 1/\lambda = 1/0.001443 = 693$ hours

Based on 16 hours of operation, the reliability of each component is calculated and shown in the reliability block diagram in Figure 6.12. The system reliability



Figures 6.12

$R_{sys} = R_1 \times R_2 \times R_3 \times R_4 \times R_5 \times R_6 \times R_7$

Substituting individual reliability, the system reliability

R_{sys} = 0.9978 x 1 x 1 x 0.9989 x 0.9934 x 0.9891 x 0.9978
= 0.9772

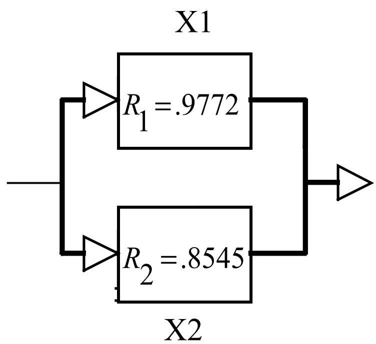
Thus the reliability of the compressor unit is 97.72% based on 16 hours of operation.

Now, let us assume that there are two compressor systems X1 and X2 in the facility, as shown in Figure 6-13, with reliability of

X1 = 0.9772

X2 = 0.8545

Figures 6.13



These reliability levels are based on 16 hours, 2-shift operation scenarios. Let us also assume that most of the time, say 85%, we need only one compressor to meet our production needs. The second compressor will work as active standby. However, for 15 percent of the time, we may need both of the compressor units. During that time, both compressors will be in series arrangement.

The reliability of one unit (85% of time needing only one compressor)

$= R_{X1} + R_{X2} - (R_{X1} \times R_{X2})$

= 0.9772 + 0.8545 – (0.9772 x 0.8545)

= 1.8317 – 0.8510

= 0.98 or 98%

The reliability of two units (15% of time needing both compressors)

$= R_{X1} \times R_{X2}$

$= 0.9772 \times 0.8545$

$= 0.8510$

So, when there is need for only one compressor unit, we are 98% reliable. However, when there is need for both compressors, we are only 85% reliable to meet customer's needs. This may be alright. If not, we may need to redesign or replace some of the components in compressor X2 to make it more reliable.

Similarly, a reliability block diagram for a process, a manufacturing line, or a plant could be developed, as in Figure 6-14. This type of reliability block diagram can provide the information needed to improve the reliability of systems in the plant.

6.3 Designing and Building for Maintenance and Reliability

Asset Life Cycle Cost

Life cycle costs (LCC) are all costs expected during the life of an asset. The term refers to all costs associated with acquisition and the ownership, specifically operations and maintenance, of the asset over its full life, including disposal. Figure 6-15 shows a typical asset life cycle chart. The total cost during the life of an asset includes:

- Acquisition Cost
    - Design and Development
    - Demonstration and Validation (mostly applicable to one-of-a-kind, unique systems)
    - Build and Installation (including commissioning)
- Operations and Maintenance (O&M)
    - Operating Cost (including energy and supplies)
    - Maintenance Cost
        - PM
        - CM
- Disposal

Based on several studies reported, the distribution of estimated LCC is as follows:

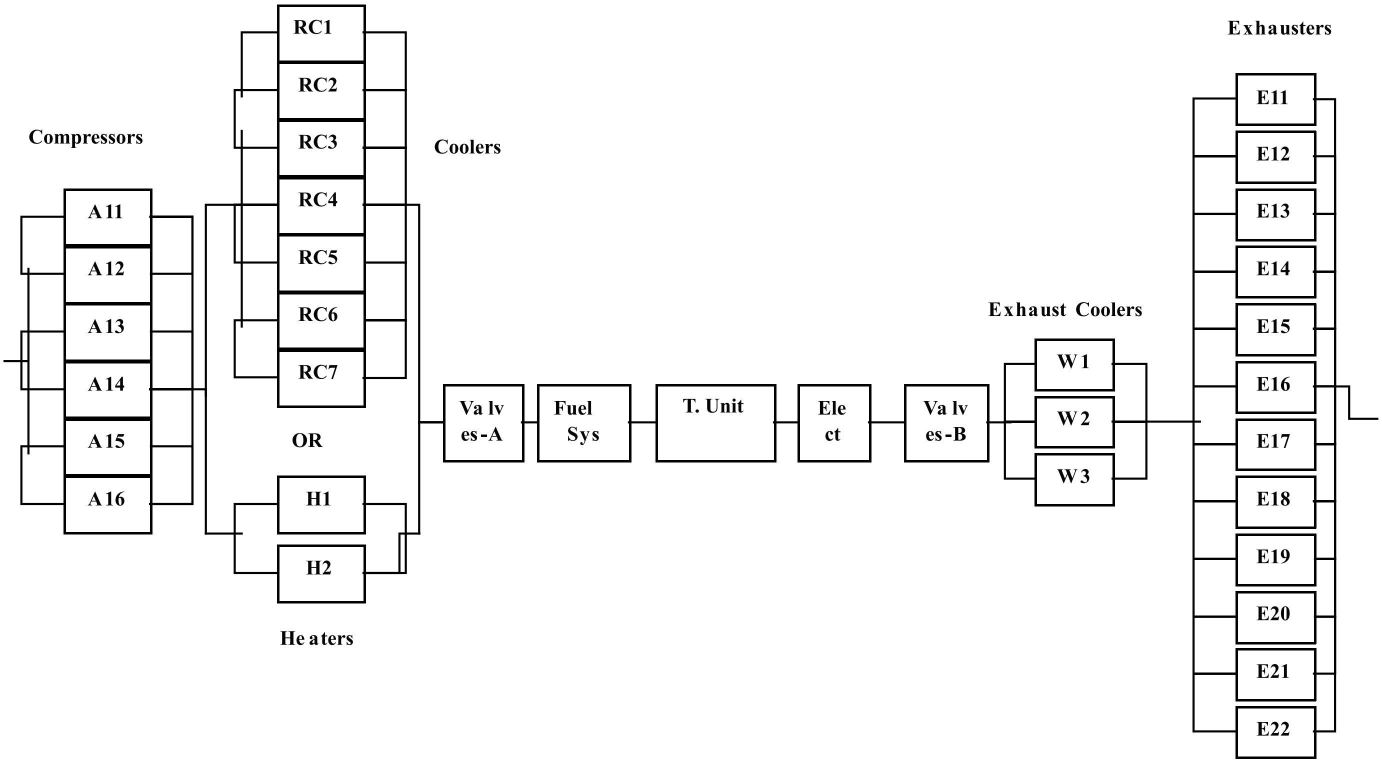
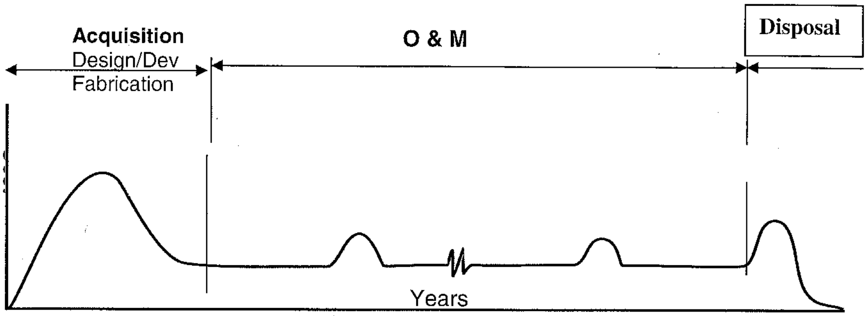


Figure 6.14 Plant Assets Reliability Block Diagram.



Figures 6.15 Asset Life Cycle

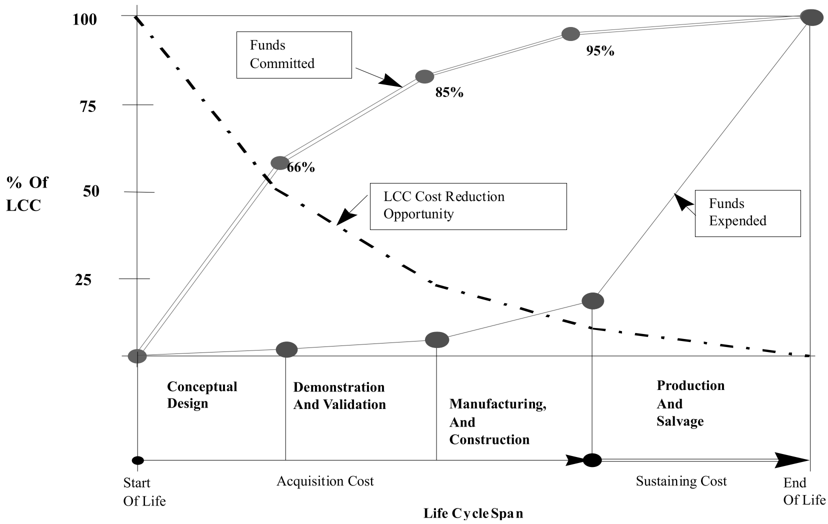
For a Typical	DoD System*	Industrial
Design and Development	10–20%	5–10%
Production / Fabrication / Installation	20–30%	10–20%
Operations and Maintenance (O&M)	50–70%	65–85%
Disposal	<5%	<5%

° Assurance Technologies Principles and Practices by Raheja & Allocco DoD –Department of Defense

A graph showing the typical cost commitment and expenditures for the life of an asset is shown in Figure 6-16, as reported by Paul Barringer, a leading reliability expert. It is clear from the figure that the O&M cost is on average about 80% of the total life cycle cost of the asset. It is obviously important that we need to minimize operations and maintenance (O&M) costs. As shown in the chart, the major portion of the O&M cost gets fixed during early design and development phase of the asset. There are ample opportunities to reduce the LCC during the design, building, and installation of the asset.

Assets should be designed so that they can be operated and maintained easily with minimum operations and maintenance needs. As discussed earlier in this chapter, reliability and maintainability are design attributes; they should be designed in, rather than added later.

To have reliable and easy-to-maintain assets, we need to insure that asset owners, including operators, are involved in developing the requirements as well as in reviewing the final design. In designing for reli-



Figures 6-16 Life Cycle Span

ability and maintainability, attention must focus on:

- Reliability requirements and specifications
- Designing for reliability and maintainability
- Proper component selection and configuration to guarantee required reliability and availability
- Review design for maintainability
- Logistics support — maintenance plan and documentation to reduce MTTR
- Reducing the operations and maintenance costs

Reliability Requirements and Specifications

In order to develop a reliable asset, there must be good reliability requirements and specifications. These specifications should address most, if not all, of the conditions in which the asset has to operate, including mission time, usage limitations, and operating environment. In many instances, developing these specifications will require a detailed description of how the asset is expected to perform from a reliability perspective. Use of a single metric, such as MTBF, as the sole reliability metric is inadequate. Even worse is the specification that an asset will be "no worse" than the existing or earlier model. An ambiguous reliability specification leaves a great deal of room for error, resulting in poorly-understood design requirements and an unreliable asset in the field.

Of course, there may be situations in which an organization lacks the reliability background or history to properly define specifications for asset reliability. In these instances, an analysis of existing data from previous or similar assets may be necessary. If enough information exists to characterize the reliability performance of a similar asset, it should be a relatively simple matter to transform this historical reliability data into specifications for the desired reliability performance of the new asset.

Indeed, the financial concerns will have to be taken into account when formulating reliability specifications. What reliability can we afford? How many failures can we live with? Do we need to have zero failures? Zero failures is a great goal, but can we justify the cost in achieving it? A proper balance of financial constraints and realistic asset reliability performance expectations are necessary to develop a detailed and balanced reliability specification.

Key Elements of Reliability Specifications

- Probability of successful performance
- Function (mission) to be performed
- Usage time (mission time)
- Operating conditions
- Environment
- Skill of operators / maintainers

An example of reliability requirements for an automotive system* consists of an engine, a starter motor, and a battery.

There shall be a 90% probability (of success) that the cranking speed is more than 85 rpm after 10 seconds of cranking (mission) at – 20 ^{O}F of (environment) for a period of 10 years or 100,000 miles (time). The reliability shall be demonstrated at 95% confidence.

Let us take another example of a manufacturing cell / system that needs to produce xyz product, at a rate of xxx / hour or day, at a quality level of Qxx, The reliability-related requirements can be developed using operational data and some assumptions. A suggested approach is :

**Assurance Technologies Principles and Practices by Raheja and Allocco*

- Operating environment / duty cycle
- 20 hours/day and 250 days/year or 5000 hours/year
- Expected # of Failures < 5/yr (This is an assumption — what can we afford? Can we live with less than 5 failures/year?)
- Reliability & Maintainability requirements (Based on above data and assumptions)
- MTBF = 5000/5 = 1000 hours; FR = 1/1000 = 0.001 failures/hr
- Estimated repair time or MTTR can be calculated based on the following assumptions
  - 3 failures @ $\leq$2 hours = 6 hours
  - 1 failure @ $\leq$10 hours = 10 hours
  - 1 failure @ $\leq$24 hours = 24 hours

Therefore, the required MTTR = 40/5 = 8 hours

- Reliability and Availability requirements
- 1 Reliability for 20 hours/day operation
  - 1 $R_{20} = e^{-(.0001x20)} = 98\%$
- 1 Availability = MTBF / (MTBF+MTTR)
  = 1000/1008 = 99%
- Operating cost
  - 2 man-hour / hour of operation (currently is 3 man-hour / hour)
  - Energy plus other utility cost 20% less than current (cur rent usage is 2 MW plus other)
- Maintenance cost (Preventive and Corrective)
  - 2% or less of Replacement Asset Value (currently 2.7%, increasing by 0.2% per year)

  Therefore, based on the calculations and data above, we can specify the following requirements for this new system we are procuring.
- MTBF of 1000 hours or FR = 0.001 failures/hr
- MTTR of 8 hours

Or we can ask reliability of 98% for 20 hours of operations/day and availability of 99%. Similarly, we can specify total operating cost and maintenance costs not to exceed some number or percent of system replacement value. However, these numbers should be validated by system designers/builder by performing FMEA.

In addition, the requirements and specifications should include:

- Display asset performance data – such as early warnings
- Current, Temperature, Pressure, etc.
- Other operating / asset condition data
- Diagnostic display — pinpointing problem areas
- Use of modular and standard components
- Use of redundant parts / components to increase reliability
- Minimize special tools — parts
- Operations and maintenance training material
- FMEA / RCM-based maintenance plan
- Maximum use of CBM technologies
- Basis of spares recommendations
- Life Cycle cost analysis
- O&M cost estimates

Reliability Approach in Design

It has been found that as much as 60% of failures and safety issues can be prevented by making changes in design. Assets must be:

- Designed for fault tolerance
- Designed to fail safely
- Designed with early warning of the failure to the user
- Built-in diagnostic system to identify fault location
- Designed to eliminate all or critical failure modes cost effectively, if possible

The following analyses are recommended to be performed during design phase — from conceptual design to final design.

- **Reliability Analysis**
    - Lowers asset and system failures over the long term
- Asset and system reliability depend on robustness of design, as well as quality and reliability of its components
- **Maintainability Analysis**
    - Minimizes downtime — reduces repair time
    - Reduces maintenance costs
- **System Safety and Hazard Analysis**
    - Identifies, eliminates, or reduces safety-related risks throughout its life cycle
- **Human Factors Engineering Analysis**
    - To prevent human-induced errors or mishaps
    - To mitigate risks to humans due to interface errors

- **Logistics Analysis**
  - Reduces field support cost resulting from poor quality, reliability, maintainability, and safety
  - Insures availability of all documentation, including PM plan, spares, and training needs

The following checklist is recommended as a guide to review the design and make sure that it adequately addresses reliability, maintainability, and safety issues.

Design Reviews Checklist

- Are reliability, maintainability, availability, and safety analysis performed?
- Is failure-mode, effect, and analysis (FMEA) performed during the design — at preliminary design reviews (PDR) and critical design reviews (CDR)?
- Can fault-free analysis be used to improve the design?
- Is fault-tolerant design considered?
- Are components interchangeabilities analyzed?
- Is modular design considered?
- Are redundancies considered to achieve desired reliability?
- Has the design been critiqued for human errors?
  - Are designers familiar with the human engineering guidelines?
- Are either ease of maintenance or maintenance-free design considered?
  - Is Reliability-Centered Maintenance (RCM) considered in design?
  - Is a throwaway type of design considered instead of repair (e.g., light bulbs)
  - Has built-in testing and diagnostics been considered?
  - Are self-monitoring and self-checking desirable?
  - Are components and assets easily accessible for repair?
- Are corrosion-related failures analyzed?
  - Do components need corrosion protection?
- Is zero-failure design economically feasible?
- Is damage detection design needed?
- Is software reliability specified and considered in design?
- Is fault-isolation capability needed?

- Do electronic circuits have adequate clearances between them?
- Are software logic concerns independently reviewed?
- Has software coding been thoroughly reviewed?
- Is self-healing design feasible or required?
- Are redundancies considered for software?
- Are the switches for backup devices reliable? Do they need maintenance?
- Are protective devices such as fuses, sprinklers, and circuit breakers reliable?
- Does the asset need to withstand earthquakes and unusual loads? If yes, are design changes adequate?
- Can manufacturing/fabrication or maintenance personnel intro duce any defects? Can they be prevented by design?
- Can the operator introduce wrong inputs — wrong switching or overloads, etc.? If so, can the asset be designed to switch to a fail-safe mode?
- Can a single component cause the failure of a critical function? If yes, can it be redesigned?
- Are there unusual environments not already considered? If haz ardous material is being used, how it will be contained or handled safely?
- Is crack growth and damage tolerance analysis required?
- Are safety margins adequate?
- Are inspection provisions made for detecting cracks, damage, and flaws?
- Are production tests planned and reviewed?
- How will reliability be verified and validated?

6.4 Summary

Improving reliability is essential to the success of any organization, particularly to its operation and maintenance. Understanding reliability and maintenance and how they're interrelated are the basis for reducing the life cycle cost of assets and plant.

Reliability focuses on the ability of an asset to perform its intended function of supporting manufacturing a product or providing a service. Reliability terminates with a failure — i.e., when unreliability occurs. Unreliability results in high cost to the organization. The high cost of unreliability motivates an engineering solution to control and reduce costs.

Maintenance is an act of maintaining, or the work of keeping the asset in proper operational condition. It may consist of performing maintenance inspection and repair to keep assets operating in a safe manner to produce or provide designed capabilities. Thus, maintenance keeps assets in an acceptable working condition, prevents them from failing, and, if they fail, brings them back to their operational level effectively and as quickly as needed.

Reliability should be designed in. It is a strategic task. In contrast, maintenance keeps the asset functioning and is a tactical task. The reliability and maintainability attributes are usually designed into the product or asset. These attributes minimize maintenance needs by using reliable components, simpler replacements, and easier inspections. Reliability is measured by MTBF, which is the inverse of failure rate. Maintainability — the ease of maintenance — is measured by MTTR.

It has been found that the Operations and Maintenance (O&M) costs are about 80% or more of the total life cycle cost of an asset. It is important to minimize O&M costs. The majority of the O&M costs to be incurred in the future are set during the design and development phase of the asset. Therefore, we must adequately address reliability, maintainability, and safety aspects of the system in order to reduce the overall life cycle cost of the assets during the design and building of the assets.

6.5 References and Suggested Reading

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Chapter 7

The Role of Operations

Reliability cannot be driven by the maintenance organization. It must be driven by the operations … and led from the top.
-- Charles Bailey

After reading this chapter you will be able to understand:

- The role of operators in sustaining and improving reliability
- Total Productive Maintenance (TPM) and its implementation
- Overall Equipment Effectiveness (OEE)
- Workplace design
- Implementation of the 5-S program to optimize productivity

7.1 Introduction

In Chapter 1, we discussed the objective of the maintenance and reliability organization: to insure that the assets are available to produce quality products and to provide quality service in a cost-effective manner when needed. The performance of an asset is based on three factors:

- Reliability (inherent) — how was it designed?
- Maintenance plan — how will it be maintained?
- Operating environment — under what environment will it work and how will it be operated?

The reliability and maintenance factors were discussed in Chapters 3 and 6. The third factor, the operating environment, will be discussed here. This factor includes the skills of the operators and the operating conditions under which the asset performs. Several studies have indicated that more than 40% of failures are the direct result of operational errors or unsuitable operating conditions. These failures, and those created by the asset itself due to faulty inherent design can be minimized or eliminated if operators have a good understanding of the asset and the way it affects the overall performance. Operators must feel responsible for the proper working of the assets under their control. They stay with the assets all the time. They live and breathe with them. They can feel if something is wrong with the proper working of the asset.

For example, consider the car you drive to work every day. If it does not sound right or starts rough, if the brakes are making a noise, or if the car takes extra distance to stop, you — as operator — will be first to notice the abnormal condition of the car. As an operator of the car (asset), you know and that something is wrong as you are driving (operating). You then take corrective actions (fix it yourself or get it repaired at a service station).

Similarly, the operator of an asset can sense if there is some thing abnormal or out of ordinary with the asset. Often these incipient problems can be corrected very cost effectively by the operator themselves or with timely help of the maintainers. However, if incipient problems are not corrected in time, they may result in bigger failures costing many times more to fix. In fact, operators should be the first line of defense in watching abnormal conditions of an asset and initiating corrective actions. But, many organizations haven’t been able to involve them successfully in maintenance because our work culture has been undergoing changes over the last several decades.

There are two primary reasons for this type of work culture:

1. Division of Operations and Maintenance labor
2. Historical reward system

A clear division of labor exists in the workforce today. The production department operates the assets and the maintenance department fixes them when they break. Maintenance is about restoring assets to an optimum operational state. For a maintenance team that has historically defined itself as the "fix-it" guys, a paradigm shift to a culture of reliability challenges their self preservation. They think, "If assets aren't failing, the value of their contribution gets unnoticed or who will value their presence?"

Likewise, operators just want to operate the assets without any regard to their maintenance needs and proper operating conditions. They sometimes have trouble seeing the overall picture. They can help in reducing the number of failures by getting involved, taking proactive actions, catching failures in early stages, and working with maintenance in timely fashion to get them attended. Thus, there is need for responsible ownership from both sides.

For decades, we have had a system of reward that has created a misaligned culture. Design teams are rewarded for achieving functional capability at the lowest cost; they usually are not really concerned about the downstream problems for operations and maintenance and the true life-cycle cost of ownership of the asset. Production teams are rewarded when they beat a production number, regardless of any real demand for the product or without any concern for the effect their actions have had on the asset health.

Maintenance teams always have been rewarded for fixing asset failures and not improving reliability or availability. They get extra pay for coming in at inconvenient times when the asset is broken and get "attaboys" from the management to fix it. If we are rewarded for failures, why would we want reliability? Who would step up and volunteer for a 15–20% pay cut for reduced overtime?

People don't pay as much attention to what their managers say with words as compared to what they actually do. If management says they want reliability — no failures or minimum failures — but they keep paying for failures, we will continue to get failures. This culture needs to be changed and improved.

The maintenance and production departments need to work together in a cohesive manner to deliver a high-quality product in a waste-free, cost-effective manner. Virtually every major management philosophy and methodology in practice today recognizes and fosters the integral relationship between the maintenance and production/operations departments. The Just-In-Time (JIT) and Lean Manufacturing methods would not be possible without high levels of asset reliability and availability, driven by active operator involvement in the maintenance process.

In this chapter, we will be discussing the role of operations in sustaining and improving the reliability and availability of the assets and systems while lowering overall cost at the same time.

Key terms and definitions used in this chapter are listed below.

Key Terms and Definitions

Availability (OEE related)

Availability is defined as the percentage of the time that an asset is actually operating (uptime) compared to how long it is scheduled to operate.

Five S (5 S)

5-S is a structured program to achieve organization-wide cleanliness and standardization in the workplace. A well-organized workplace results in a safer, more efficient, and productive operation. It consists of five elements: Sort, Set in Order, Shine, Standardize, and Sustain.

Operator Driven Reliability (ODR)

Involving equipment operator to improve reliability by identifying potential equipment problems and failures early. Then operator fixes them if minor and gets them repaired if major, with the help of maintenance in a planned manner. ODR is also called Operator-Based Reliability (OBR) or Operator-Based Maintenance (OBM)

Overall Equipment Effectiveness (OEE)

OEE is a metric for measuring how well an asset or process is operating. It evaluates three process factors: availability, performance, and quality. OEE is calculated by multiplying these three factors and then expressed as a percentage. The objective of OEE is to identify sources of loss, waste, and inefficiencies that reduce availability, performance and product quality (defects). Corrective actions can then be taken to improve the process.

Total Productive Maintenance (TPM)

TPM is a maintenance strategy that emphasizes operations and maintenance cooperation. Its goal includes zero defects, zero accidents, zero breakdowns, and an effective workplace design to reduce overall operations and maintenance costs.

Total Effective Equipment Performance (TEEP)

TEEP is a measure of an asset's or process's productivity. It's based on four factors: utilization, availability, performance, and quality. TEEP is calculated by multiplying these four factors and then expressed as a percentage. It can also be calculated by multiplying the utilization rate with OEE. The objective of TEEP is to measure how well an organization creates lasting value from its assets. Most of the time, it considers that the assets are capable of operating productively 24 hours a day, 365 days a year. In reality, it will not be possible to achieve 100% TEEP.

Utilization Rate

The percentage of time an asset is scheduled to operate divided by the total available time, which could be 24 hours a day, 365 days a year.

Visual workplace

A visual workplace uses visual displays to relay information to employees and guide their actions. The workplace is set-up with signs, labels, color-coded markings, etc., so that anyone unfamiliar with the assets or process can readily identify what is going on, understand the process, and know both what is being done correctly and what is out of place.

On the following page Figure 7.1 will provides a list of Japanese words and definitions that have a special industrial meaning.

7.2 The Role of Operations

The concept of Operator Driven Reliability (ODR) — sometimes called Operator-Based Reliability or OBR — is an integral part of an overall proactive maintenance strategy.

The objective of ODR is to help keep plants running better, longer, cost-effectively, and competitively by reducing unplanned downtime and increasing uptime of production processes and associated assets.

M&R Related Japanese Words & Definitions

- **Bekidou –** Output optimization
- **Gemba** – Workplace
- **Kanban** – A card/sheet or visual device to signal readiness to previous process
- **Karoshi** – Death from overwork
- **Kaizen** - continuous improvement
- **Ketten** – flaw or defect
- **Jidoka** - Automation with human intelligence (*Autonomation*).
- **Muda** – Waste (deadly waste –Overproduction, waiting, inventory etc..)
- **Mura** – Inconsistencies
- **Muri** – Unreasonableness
- **Heijunka** –A system of production smoothing designed to achieve more even and consistent flow of work.
- **Poka Yoke** – a mistake-proofing device to prevent a defect
- **Sensei** – One who provides information (Teacher, person having advance knowledge)
- **Seiri** (Sort) - Going through all the tools, materials, etc., and keeping only essential items.
- **Seiton** (Set in Order) - Focuses on an orderly workplace.
- **Seisō** (Shine) - Systematic Cleaning or the need to keep the workplace clean as well as neat.
- **Seiketsu** (Standardizing) - Standardized work practices
- **Shitsuke** (Sustain) – Sustaining what has been achieved
- **Seisan** – Production or manufacture

- **KARAOKE:** literally "empty orchestra," a form of entertainment in which people sing popular songs against recorded back-up music.

Figure 7.1

By proactively identifying problems, operators can eliminate or reduce failures, thereby increasing reliability. Owning and operating assets constitutes one of the biggest factors in the total cost in a plant. Reducing that cost by increasing asset uptime can generate additional profits without any additional expenditures.

Under the ODR concept, operators perform basic maintenance activities beyond their classic operator duties. They take responsibility to observe and record the asset's overall health by checking for leaks and noises, monitoring temperature, vibration, and any abnormal asset/system conditions. In some cases, operators correct the minor deficiencies they find. They perform tasks such as cleaning, minor adjustments, lubrication, and simple preventive and corrective tasks traditionally handled by the maintenance technician. These tasks represent a departure from their traditional role as just an equipment operator. ODR encourages production to interact with maintenance and other departments as a team to reduce the number of failures, thus improving plant-wide asset reliability.

In most cases, the original equipment manufacturers (OEM) recommend how equipment should be operated. OEM recommendations are sometimes made without any understanding or appreciation for the process or environment in which the asset is actually operated. OEM also has very little or no knowledge of the operator's skill sets. Usually they also require operators and maintainers to do a lot more than what really is needed to preserve the asset's functions. This may result in too many PM tasks and unnecessary inspections as well as time wasted collecting irrelevant information.

With operators taking responsibility for identifying problems, the probability of detecting asset failures early rises exponentially. This improvement can contribute to increased asset reliability at much lower cost due to earlier fault detection.

In many organizations, maintenance and operations departments function virtually independently of each other, effectively divorced with separate agendas. Such situations do not go well for organizations striving to improve productivity and profitability. ODR can serve as a bridge to those achievements by fostering and promoting internal dialogue and offering a cost-effective way to improve asset reliability. ODR can encourage a culture that will not tolerate failures; it can maximize cross-functional teamwork and identify many previously hidden opportunities for continuous improvements.

The ODR concept is similar to another maintenance strategy known as Total Productive Maintenance (TPM) which was developed in Japan in the early 1960s. TPM will be discussed in detail in the next section.

7.3 Total Productive Maintenance (TPM)

Total Productive Maintenance (TPM) is a team-based asset management strategy that emphasizes cooperation between operations and maintenance departments with a goal of zero defects, zero breakdowns, and an effective workplace design.

TPM seeks to engage all levels of an organization with their different functions in an effort to maximize the overall effectiveness of production assets. This helps to bring improvements in existing processes and asset availability by reducing mistakes and accidents. Traditionally, the maintenance department manages the plant's maintenance programs, but TPM seeks to involve employees in all departments — including production and maintenance at all levels from the plant-floor to senior executives — to insure effective asset operation.

TPM is based around the following principles:

- Improving asset and equipment effectiveness
- Autonomous maintenance by operators
    - Servicing, adjustments, and minor repairs
- Planned maintenance by maintenance department
- Training to improve operation and maintenance skills
- Better workplace design including standardization of procedures and cleanliness

TPM is an innovative Japanese concept. The origin of TPM can be traced back to the 1960s when preventive maintenance was introduced in Japan. Nippondenso, a Toyota part supplier, was the first company to introduce a plant-wide preventive maintenance program in 1960. However later with the increasing automation of assets and systems at Nippondenso, the maintenance program needed to perform additional work; more maintenance personnel were required. Management decided that the routine maintenance of equipment would be carried out by the equipment operators themselves. The maintenance group took the responsibility for major repairs and essential maintenance tasks. This practice later was called autonomous maintenance, which became one of the pillars of TPM.

In this model, after establishing a preventive maintenance program, Nippondenso also added the autonomous maintenance work to be done by the equipment operators. The maintenance department concentrated on equipment PMs and process modifications for improving reliability. These improved modifications were also incorporated in new equipment designs leading to the reduction or prevention of maintenance work. Thus *preventive maintenance*, along with *maintenance prevention* and *design improvement*, gave birth to *Productive Maintenance*. The aim of productive maintenance was to maximize plant and equipment effectiveness to achieve the optimum life cycle cost for production equipment.

Nippondenso was also involved in forming quality circles, which facilitated the employee's participation in improving quality of their products. All Nippondenso employees got involved in implementing Productive Maintenance. Because all (or the total) plant employees participated in implementing productive maintenance, Seiichi Nakajima of the Japanese Institute of Plant Engineers (JIPE), who led this effort, named the concept Total Productive Maintenance (TPM). Based on these developments, Nippondenso was awarded the distinguished plant prize for developing and implementing TPM. Thus Nippondenso of the Toyota group became the first company to obtain the TPM certification.

The TPM program closely resembles the popular Total Quality Management (TQM) program. Many of the tools used in TQM, such as employee empowerment, benchmarking, and documentation, are also used to implement and optimize TPM. The following shows the similarities between the two programs.

1. Total commitment to the program by upper level management.
2. Employees must be empowered to initiate corrective action
3. A long-term strategy is required as it may take a long time to implement programs and make them a part of the routine, ongoing process
4. Cultural change — new mindsets are required

Right from the start, TPM requires effective leadership and involvement of *all* employees from a craft person to senior managers. That is part of the meaning of "total" in Total Productive Maintenance. TPM holds people accountable for performing highly specified (or specialized) work and improved equipment performance. Without management support, TPM will become a program of the month, and will die. Many of today's business leaders have risen through the ranks when maintenance was responsible only for fixing things and not also for preventing failures. Viewing maintenance as a non-value-adding support function often leads to severe cost-cutting measures; this step in turn results in higher costs due to decreased equipment effectiveness.

TPM Objective and Benefits

The objective of TPM is to:

1. Achieve zero defects, zero breakdowns, and zero accidents in all functional areas of the organization.
2. Involve people at all levels of organization.

These goals are accomplished by involving all employees in small group activities that identify both the causes of failures and opportunities for plant and equipment modifications. They are also accomplished by adopting the life cycle approach for improving the overall performance of production equipment.

Benefits of TPM

1. Increased productivity
2. Reduced manufacturing cost
3. Reduction in customer complaints.
4. Satisfy the customer's needs by 100%
    a. Delivering the right quantity
    b. At the right time
    c. With best, required quality
5. Reduced safety incidents and environmental concerns.

In addition, TPM creates a positive work culture and environment to:

- Build a higher level of confidence among the employees
- Keep the work place clean, neat, and attractive
- Favorable / positive attitude of the operators and maintainers
- Deployment of a new concept in all areas of the organization
- Share knowledge and experience

The employees get empowered and have real sense of owning assets.

TPM Pillars

TPM consists of eight pillars of activities that impact all areas of the organization. Theses pillars are:

Pillar #1 Autonomous Maintenance (Jishu Hozen)

This pillar is geared towards developing operators to be able to take care of small maintenance tasks. This ability in turn frees up the skilled maintenance people to spend time on higher value-added activities and technical repairs, instead of fire-fighting, breakdown maintenance. Under this concept, operators are responsible for upkeep of their equipment to prevent them from deterioration-causing breakdowns.

Implementing autonomous maintenance requires not only a change in organization culture, but also a heavy investment in training. Operators who have always said "That's not my job — call maintenance," must now acquire a sense of ownership. They must also acquire the skills to properly implement their new accountability. Operators will now keep the equipment clean, lubricated, and secure. Minor repairs and adjustments also become part of operator responsibility. Operators need to be trained to inspect, measure, and continuously diagnose and fix problems.

In carrying out these responsibilities, operators need to learn more about their equipment and become better equipped to detect problems early. Therefore, they take corrective action at the right time and become key members of the team to improve equipment effectiveness.

Management must promote a working environment that fosters positive change. This change can be accomplished through their increased involvement in the program, by providing physical surroundings conducive to work. Positive change also requires monetary support for the TPM program and for implementation of the ideas it generates.

The goals of autonomous maintenance are:

- Uninterrupted operation of equipment
- Operators to operate and maintain the equipment
- Elimination of the defects and potential failures at source quickly
- Involvement of all employees to solve problems through active participation

Five S (5 S), also known as workplace organization, is an important practice. To some authors, it is a part of the autonomous maintenance pillar. To others it is a separate pillar by itself. But 5 S is a key element of operator driven reliability and a foundation of TPM. We will be discussing this in more detail in Section 7.4.

Overall equipment effectiveness (OEE) is a key metric in determining how well equipment is performing with regards to losses. OEE measures equipment effectiveness in terms of availability, performance, and product quality. Details of OEE will be discussed in Section 7.5.

Pillar #2 Focused Improvement — Kaizen (Kobetsu)

This pillar is aimed at reducing losses in the workplace to improve operational efficiencies. Kai' means change, and Zen means good. Kaizen is a collection of small improvements that produces amazing results when carried out on a continual basis; it involves all employees in a group or team.

The goals of Kaizen improvement are:

- Zero losses — identify and eliminate losses
- Improve effectiveness of all equipment and plant
- Reduce O&M costs

The following are six major losses that can become a focus of kaizen teams to improve effectiveness:

1. Breakdown losses
2. Setup and adjustment losses
3. Idling and minor stoppage losses
4. Speed losses
5. Defective product losses (quality) and rework
6. Equipment design losses

Breakdown losses Breakdown losses are equipment-related losses resulting from failures, breakdowns, and repairs. Costs can include downtime and lost production opportunity, labor, and material costs.

Set-up and adjustment losses These losses result from equipment set-ups and adjustments that occur during product changeovers, shift changes, or other changes in operating conditions.

Minor Stoppage losses These losses are the result of short but frequent production stoppages from zero to few minutes in length (less than 5–6 minutes). They are usually difficult to record. As a result, these losses are usually hidden from production reports. These are built into machine capabilities, but provide substantial opportunities for improving production efficiencies.

Speed losses Sometime equipment must be slowed down to prevent quality defects or minor stoppages, resulting in production losses. In most cases, this loss is not recorded because the equipment continues to operate.

Quality defect losses These losses result from out-of-spec production and defects due to equipment malfunction or poor performance, leading to output which must be reworked or scrapped as waste.

Equipment design losses These losses are typical of heavy wear and tear on equipment due to"non-robust" design, which reduces their durable and productive life span. Such designs lead to more frequent equipment modifications and capital improvements.

By using a detailed and thorough analysis, equipment design losses are reduced or eliminated in a systematic manner using tools such as Pareto, Why Why Analysis, and Failure Mode and Effects Analysis (FMEA). The use of such tools are not limited to production areas but can be employed in administrative and service areas as well to eliminate losses or waste.

Pillar #3 Planned Maintenance

Planned maintenance and improvement are carried out by the maintenance department. These planned maintenance tasks are usually beyond the scope of the autonomous maintenance program. They require special skills, significant disassembly, special measuring techniques and tools, etc. As equipment operators improve their skills, the maintenance group performs fewer and fewer planned maintenance activities and start focusing their efforts instead on improvements that are designed to reduce the maintenance requirement of the equipment, thus reducing overall maintenance work.

Pillar #4 Quality Maintenance

This pillar focuses on eliminating product quality related to non-conformances in a systematic manner. As operators gain understanding of how various components of equipment affect the product quality, they begin to eliminate the current quality issues and then prepare to tackle potential quality concerns. At this point, operators start making the transition from a reactive to proactive approach, that is, from quality control to quality assurance.

The aim is to delight customers by providing the highest quality products while at the same time achieving defect-free production.

Pillar #5 Training and Development

Under this pillar we assess technical training needs, determine the current status of skill sets, and establish a training plan based on the gap analysis. The goal is to have a multi-skilled workforce and to create a cadre of experts for supporting all aspects of TPM.

The purpose of providing training is to upgrade the skill set of operators. It is not sufficient to have only "Know–How" skills. They must also "Know–Why." Appropriate training can improve their skill sets to perform root cause analysis and other tasks required to improve equipment effectiveness and reduce costs.

Pillar #6 Design and Early Equipment Management

In this pillar, the lessons of successes and failures of TPM activities are incorporated in the design of new equipment and products. The goal is to produce almost perfect equipment and better quality products by taking care of inefficiencies and safety issues during the design, build, and commissioning processes.

Maintenance Prevention (MP), which is Design and Early Equipment Management, involves discovering weak points in the currently-used equipment and feeding this information back to the equipment design engineers. It is similar to design for manufacturability. MP design takes the following factors into consideration:

1. Ease of autonomous maintenance (operator maintenance)
2. Ease of operation
3. Ease of maintenance — improving maintainability
4. Improving quality
5. Safety

Early equipment management is a system for dealing with problems that surface during the commissioning and start-up of new equipment. During this period, engineering personnel from production and maintenance / reliability must correct problems caused by poor selection of materials at the design stage and by errors occurring during fabrication and installation of the equipment.

Pillar #7 Office Improvement

In this pillar, the objective is both to eliminate efficiency losses in the office and service areas and to implement tool such as 5S in order to create an organized and efficient office environment. This can be aimed at logistics, scheduling, HR, accounting, and other areas of the plant administrative support.

Pillar #8 Safety, Health, and Environment

In this pillar, the focus is on the 100% elimination of accidents as well as on employee health and environmental concerns. The focus is to create a safe workplace and surroundings with the following goals:

- Zero accidents
- Zero health concerns (damage)
- Zero fires

Many consider this pillar the base of all the pillars.

Implementing TPM

Many successful organizations usually follow an implementation plan that includes the following 10 steps:

Step 1: Announcement of TPM.

Top management needs to create an environment that will support the introduction of TPM. Without the support of management, skepticism and resistance will kill the initiative.

Step 2: Launch a formal education program.

This program informs and educates everyone in the organization about TPM activities, benefits, and the importance of contribution from everyone.

Step 3: Create an organizational support structure.

This group will promote, coordinate, and sustain team-based TPM activities. It needs to include members from every level of the organization — from management to the shop floor. This structure will promote communication and will guarantee everyone is working toward the same goals.

Step 4: Establish basic TPM policies and quantifiable goals.

Analyze the existing conditions, then establish TPM policies and set attainable and realistic goals.

Step 5: Outline a detailed master deployment plan.

This plan will identify what resources will be needed as well as when they will be needed for training, equipment restoration and improvements, maintenance management systems, and new technologies.

Step 6: TPM kick-off.

TPM implementation will begin at this stage.

Step 7: Improve the effectiveness of each piece of equipment.

Operations and Maintenance Kaizen teams will analyze each piece of equipment and implement necessary improvements on a continuing basis.

> **Step 7a: Develop an autonomous maintenance program for operators.** Operators will routinely clean, inspect, and perform minor maintenance tasks that will help to stabilize and improve equipment conditions.
>
> **Step 7b: Develop a planned or preventive maintenance program.** Create a schedule for preventive maintenance on each piece of equipment.
>
> **Step 7c: Identify losses / waste and implement reduction plan.** Create Kaizen teams to eliminate or reduce waste.

Step 8: Conduct training to improve operation and maintenance skills.

The maintenance department will take on the role of trainers or guides and provide training, advice, and equipment information to the operators (Kaizen teams).

Step 9: Develop an early equipment management program.

Lessons learned in operations and maintenance should be communicated to the design process of new equipment development. Reliability and maintainability should be built into the new design.

Step 10: Continuous improvement.

As in any lean initiative, the organization needs to develop a continuous improvement mindset.

7.4 Work Place Organization: 5 S

Five S (5S) is a technique to reduce waste and optimize productivity by maintaining an orderly workplace and using visual cues to achieve more consistent operational results. 5 S promotes a cleaner environment and a better organized workplace.

It is a structured program to achieve total organization-wide cleanliness and standardization in the workplace. A well-organized workplace results in a safer, more efficient, and more productive operation. It boosts the morale of the employees, promoting a sense of pride in their work, and a responsible ownership of their equipment.

5 S was invented in Japan and stands for five (5) Japanese words that start with the letter S: Seiri, Seiton, Seiso, Seiketsu, and Shitsuke. An equivalent set of five S words in English has been adopted by many to preserve the 5 S acronym in Japanese. These are:

S1 Sort (Seiri)
S2 Set in Order (Seiton)
S3 Shine (Seiso)
S4 Standardize (Seiketsu)
S5 Sustain (Shitsuke)

S1 Sort (Seiri)

Sort is the first step in making a work area tidy. It refers to the act of throwing away all unwanted, unnecessary, and unrelated materials in the workplace and freeing up additional space. This step makes it easier for operators and maintainers to find the things they need. This step requires keeping only what is necessary. Materials, tools, equipment, and supplies that are not frequently used should be moved to a separate, common-storage area. Items that are not used should be discarded. Don't keep things around just because they might be used someday.

As a result of the sorting process, we will eliminate (or repair) broken equipment and tools. Obsolete fixtures, molds, jigs, scrap material, waste, and other unused items and materials are discarded.

People involved in Sort must not feel sorry about having to throw away things. The idea is to insure that everything left in the workplace is related to work. Even the number of necessary items in the workplace must be kept to its absolute minimum. Because of the Sort concept, the simplification of tasks, effective use of space, and careful purchase of items will follow.

S2 Set-in-Order (Seiton)

Set-in-order or orderliness is Step two and is all about efficiency. It requires organizing, arranging, and identifying everything in a work area. Everything is given an assigned place so that it can be accessed or retrieved quickly, as well as returned in that same place quickly. If everyone has quick access to specific items or materials, work flow becomes efficient, and the worker becomes productive. The correct place, position, or holder for every tool, item, or material must be chosen carefully in relation to how the work will be performed and who will use which items. Every single item must be allocated its own place for safekeeping. Each location must be labeled for easy identification of its purpose.

Commonly-used tools should be readily available. Properly label storage areas, cabinets, and shelves. Clean and paint floors to make it easier to spot dirt, waste materials, and dropped parts and tools. Outline areas on the floor to identify work areas, movement lanes, storage areas, finished product areas, etc. Put shadows on tool boards, making it easy to quickly see where each tool belongs.

In an office environment, provide bookshelves for frequently-used manuals, books, and catalogs. Label the shelves and books so that they are easy to identify and return to their proper place.

Again, the objective in this step is to have a place for everything and everything in its place, with everything properly identified and labeled.

Many M&R professional have started calling these practices of using labels, color-coded markings, etc., a visual workplace; it helps operators. In fact, it helps anyone unfamiliar with the asset or process to readily identify what is going on, understand the process, and know what is to be done correctly and what is out of place. A visual workplace uses visual displays to relay information to operators and other employees, and to guide their actions.

Figure 7.2 shows examples of a visual workplace. Figure 7.2a indicates safe operating parameters for oil and pressure levels and also when to tighten the chain or belt. Figure 7.2b displays an organized tool

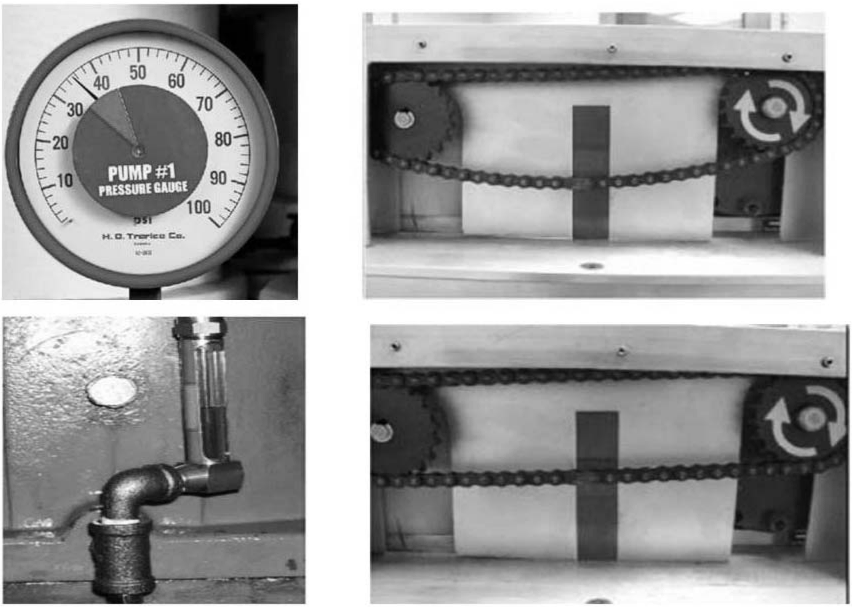

Figure 7.2a

Figure 7.2b

ASME A13.1 - 2007 Standard for the Identification of Pipes

Material Properties & Label Colors

Material	Description	Label Color
TOXIC & CORROSIVE	Fluids which are corrosive, toxic or will produce corrosive or toxic substances.	Black on Orange
COMBUSTIBLE	Fluids that may burn but are not flammable.	White on Brown
FLAMMABLE	Fluids which are a vapor or produce vapors that can ignite and continue to burn in air.	Black on Yellow
FIRE QUENCHING	Water and other substances used in sprinkler fire fighting piping systems.	White on Red
OTHER WATER	Any other water except for water used in sprinkler & fire fighting piping systems.	White on Green
COMPRESSED AIR	Any vapor under pressure that does not fit a category above.	White on Blue
DEFINED BY USER	It is up to the company's discretion.	White on Black
DEFINED BY USER	It is up to the company's discretion.	Black on White
DEFINED BY USER	It is up to the company's discretion.	White on Purple
DEFINED BY USER	It is up to the company's discretion.	White on Gray

Outside Pipe Diameter Including Covering		Minimum Length of Label Field Color		Minimum Height of Letters	
Inches	mm	Inches	mm	Inches	mm
3/4 to 1 1/4	19 to 32	8	203	1/2	13
1 1/2 to 2	38 to 51	8	203	3/4	19
2 1/2 to 6	64 to 152	12	305	1 1/4	32
8 to 10	203 to 254	24	610	2 1/2	64
over 10	over 254	32	813	3 1/2	89

Standard Color Code

Category	Color	Uses
Safety	Green	Safety Equipment, First Aid, Safety Posters, Recycle Containers, Exits, OSHA Compliance
Equipment & Inventory	Blue	Machines, Inventory Lines & Signs, Inspection Points, Notices, OSHA Compliance
Standards	Yellow or Orange	Machine Guards, Aisle Walkways, Operation Standards, Handrails & Guardrails, Cautions, Warnings, OSHA Compliance
Defects & Fire	Red	Scrap Containers, Fire Fighting Equipment Locations, Sprinkler Piping, Tags For Unused Items
Total Process Management	White	Repair Tools, Total Process Management Materials, Cleanliness
Racks & Storage	Gray	Racks, Warehouse, Mold Skids

This is a suggested color scheme for color-coding your facility. It does not correspond to any standard. Other colors may be used.

Figure 7.2c

figure 7.2d

box and provides examples of labels applied to a switch box and a Danger Area. Figure 7.2c demonstrates the ASME standard color code scheme suggested for piping. Figure 7.2d shows examples of color-coded pipes and hoses.

S3 Shine (Seiso)

Shine is all about cleanliness and housekeeping. The Seiso principle says that everyone is a janitor. The step consists of cleaning up the workplace and giving it a shine. Cleaning must be done by everyone in the organization, from operators to managers. It would be a good idea to have every area of the workplace assigned to a person or group of persons for cleaning. Everyone should see the workplace through the eyes of a visitor — always thinking if it is clean enough to make a good impression.

While cleaning, it's easy to inspect the equipment, machines, tools, and supplies we work with. Regular cleaning and inspection makes it easy to spot lubricant leaks, equipment misalignment, breakage, missing tools, and low levels of supplies. Problems can be identified and fixed when they are small. If these minor problems are not addressed while small, they could lead to equipment failure, unplanned outages, or long, unproductive waits while new supplies are delivered.

When done on a regular, frequent basis, cleaning and inspecting generally will not take a lot of time. In the long run, they will most likely save time.

S4 Standardized (Seiketsu)

The fourth step is to simplify and standardize. Seiketsu translates to standards for all operational activities, including cleanliness. It consists of defining the standards by which personnel must measure and maintain operating and maintaining standards such as lubrication plan, filter change out instructions, or measures of cleanliness. Visual management is an important ingredient of Seiketsu. Color-coding and standardized coloration of surroundings are used for easier visual identification of anomalies in the surroundings. Employees are trained to detect abnormalities using their five senses and to correct such abnormalities immediately.

One of the hardest steps is avoiding old work habits. It's easy to slip back into what we have been doing for years. That's what everyone is familiar with. It feels comfortable.

The good practices developed in earlier steps should be standardized and made easy to accomplish. As we learn more, update and modify the standards to make the process simpler and easier.

S5 Sustain (Shitsuke)

The final step is to sustain the gain by continuing education, training, and maintaining the standards. In fact, Shitsuke means discipline. It promotes commitment to maintaining orderliness and to practicing the first 4 S as a way of life. The emphasis of Shitsuke is elimination of bad habits and constant practice of good ones.

Continue to educate people about maintaining standards. When there are changes such as new equipment, new products, and new work rules that will affect the 5 S program, adjustments will be needed to accommodate those changes, modify changes in the standards, and to provide training that addresses those changes.

If your organization is planning to implement Lean Manufacturing, 5 S is one of the first activities that needed to be carried out on their Lean adoption.

Some organizations have added a sixth S to emphasize safety in their program and call it 5 S plus or 6 S program

7.5 Performance Measures: Metrics

Overall Equipment Effectiveness (OEE) is a key metric used in TPM and Lean Manufacturing programs to measure the effectiveness of TPM and other initiatives. It provides an overall framework for measuring production efficiency. OEE is the traditional and most widely-used metric to measure equipment and assets productivity based on actual availability, performance efficiency, and product quality. However, true equipment productivity is measured by Total Effective Equipment Performance (TEEP), which is based on 24 hours per day and 365 days per year operations. TEEP also considers equipment utilization.

OEE and TEEP measure the overall utilization of assets and equipment for manufacturing operations, directly indicating the gap between actual and ideal performance. OEE quantifies how well a manufacturing unit performs relative to its designed capacity, during the periods when it is scheduled to run. TEEP measures how well an organization creates value from its assets by effective utilization based on 24 hours per day, 365 days per year availability.

OEE and TEEP are calculated as:

OEE = Availability X Performance X Quality

TEEP = Utilization X Availability X Performance X Quality

TEEP = Utilization X OEE

Overall Equipment Effectiveness

OEE breaks the performance of an asset into three separate but measurable elements: availability, performance, and quality. Each element points to an aspect of the process that can be targeted for improvement. OEE may be applied to any individual asset or to a process. It is unlikely that any manufacturing process can run at 100% OEE. Many manufacturers benchmark their industry to set a challenging target; 85% is not uncommon.

Calculating OEE

OEE = Availability x Performance x Quality

Example 7.1

A given asset, a machining center, experiences the following:

Availability of asset = 88.0%

Asset Performance = 93.0%

Quality it produces = 95.0%

OEE = 88% (Availability) X 93% (Performance) X 95% (Quality)
= 77.7%

Calculating TEEP

TEEP = Utilization X Availability X Performance X Quality

Example 7.2 Whereas OEE measures effectiveness based on scheduled hours, TEEP measures effectiveness against 24 hours per day, 365 days per year operation. In the example above, suppose this same asset — the machining center — operates 20 hours a day, 300 days in a year.

OEE of machinating center (calculated above) = 77.7%

Machining Center Utilization

= (20 hours X 300 days) / (24 hours X 365 days) = 68.5%

TEEP = 68.5% (Utilization) X 77.7% (OEE) = 53.2%

Figure 7.3 illustrates the concept of OEE and TEEP and how different production losses impacts productivity.

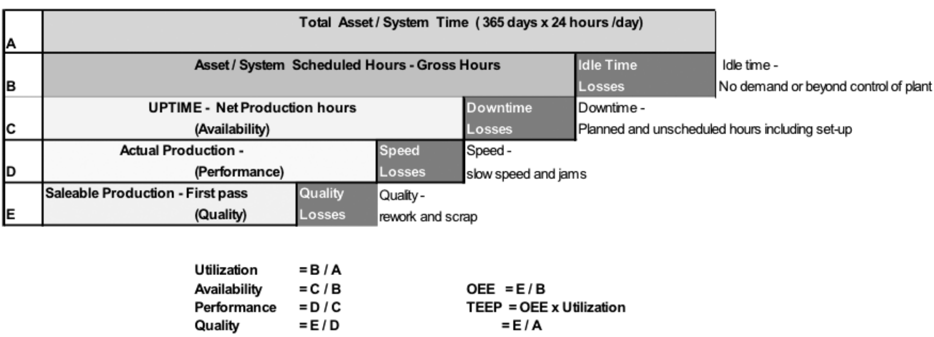

Figure 7.3 OEE and TEEP

Example 7.3 A six-station hammer assembly machine shows the following operational data from CMMS and operational log of assembly machine.

Machine Cycle Time (design): 1 unit/minute
Scheduled Time: Two 10-hour shifts/day and 250 days/year = 5, 000 hours/year

Note that 5 days of production were cancelled in the year, including 4 days due to lack of wood handles (raw material) and one day due to loss of electric power resulting from a winter storm.

Scheduled Downtime :

5 PMs, each at 1000 operating hours, each requiring 8 hours of downtime (16 man hours of per PM)

1 PM at 5000 operating hours, requiring 10 hours of downtime (40 man hours per PM)
50 weekly checks by operators, 30 minutes each
10 planned repairs requiring a total of 55 hours of downtime
50 models set ups, 2 hours each
Unscheduled Downtime:
8 failures resulting in
50 hours of downtime (132 man hours of failure repair work)
22 setups and tooling changes resulting in 20 hours of downtime
Performance Losses:
Minor stoppages / jams (Less than 5 min each)
750 instances per year — average 3.2 minute each

During winter (about 120 days in year), the system runs slower in the morning for 30 minutes. This increases the machine cycle time from 1 unit/minute to 1 unit / 1.5 minutes during this period.

Quality Losses:

On average, every hour the assembly unit produces 57 good quality units, 2 units needing some repair, and 1 scrap unit.

Calculate OEE and TEEP for this assembly system.

Asset Utilization

Ideally, total hours available for production
= 365 days X 24 hours/day = 8,760 hours /year
Idle hours = Hours asset doesn't run due to lack of demand or factors beyond the control of asset/plant.
= (4 hours/day X 250 days) + [24 hours X (365 – 250) days] + (24 hours X 5 days)
= 1,000 + 2760 + 120
= 3880 hours

Gross hours of scheduled production
= Total available hours – Idle hours
= 8760 – 3880 = 4880 hours /year
Asset utilization rate
= Gross hours of scheduled production / Total available hours
= 4880 / 8760 = 55.7%

Asset Availability

Asset availability (%) = Uptime x 100 / (Uptime + Downtime)

Uptime hours = Gross hours of scheduled production – Downtime hours

Downtime hours = Scheduled and unscheduled downtime hours

Scheduled downtime hours

= (5 x 8) + 10 + (50 x 0.5) + 55 + (50 X 2) = 230 hours

Unscheduled downtime hours = 50 + 20 = 70 hours

Total downtime hours = 230 + 70 = 300 hours

Uptime hours = 4880 – 300 = 4580 hours

Asset availability (%) = 4580 / (4580 + 300) = 93.9%

Asset Performance

Asset performance – Efficiency in %

= Actual production rate / Designed (best) Production rate x 100

Designed production rate or Cycle time

= 1 minute /unit (60 units per hour)

Performance losses

Minor stoppages (Hours/year) = 750 X 3.2 min = 40 hours

Speed losses (machine running slow)

= 120 x 0.5 x [(1.5 - 1) / 1.5] = 20 hours/year

Total Performance losses (Hours/year) = Minor stoppages + Speed losses

= 40 + 20 = 60 hours

Performance Efficiency %

= (Uptime hours – Performance losses) / Uptime hours

= (4580-60) / 4580 = 98.7%

Quality Losses

The quality portion of the OEE represents the good units produced as a percentage of the total units. The quality performance is a pure measurement of process yield that is designed to exclude the effects of availability and performance.

On average, the hammer assembly machine produces 57 good units per hour out of 60. The other 3 units are usually reworked or scraped.

Quality Performance (%) = 57 / 60 = 95%

OEE for hammer assembly machine
= Availability X Performance X Quality
= 93.9% X 98.7% X 95% = 88.0%

TEEP for hammer assembly machine
= Utilization X OEE
= 55.7% X 88.0% = 49.0%

7.6 Summary

Reliable equipment operating at the lowest possible cost is an essential enabler of an organization's profit. Asset and plants are often the single largest investment; it would make sense that asset reliability should be as important to the organizations as are environment, health, quality, and safety. But asset reliability has not received its due emphasis in the past. Operator Driven Reliability (ODR) and Total Productive Maintenance (TPM) strategies encourage participation of all employees, specifically operators, and provide a framework for policies, procedures, and structure to have assets available and operated at the lowest cost possible.

By making equipment more efficient, TPM is focused on keeping assets functioning optimally and minimizing equipment breakdowns and associated waste. Autonomous maintenance, a key pillar of TPM, seeks to eliminate major losses that can result from faulty equipment or operation by involving operators in maintenance of equipment they operate. Under the TPM concept, equipment operators become owners of their assets. Working closely with maintenance, they take care of all details that will preserve the assets in the best possible condition.

TPM has eight pillars of activity, with an ultimate goal of zero breakdowns and zero accidents. These pillars are:

1. Autonomous maintenance
2. Focused improvement — Kaizen
3. Planned maintenance
4. Quality maintenance
5. Training and development
6. Design and early equipment management
7. Office improvement
8. Safety, health, and environment

Under autonomous maintenance, which is a key pillar, operators clean and lubricate the equipment and execute the recommended maintenance plan. They are empowered to modify the program according to the real needs and personal observations. The operator has access to the manufacturer specifications and the support of the maintenance technicians.

The operators also become responsible for small adjustments, checking for parts that become loose, and fixing them, as well as reporting small details like noises, vibrations, or temperature rises while operating the equipment.

An important factor in the success of the TPM program is the pride that operators experience from the optimal condition in which their equipment is preserved. A great deal of this improved effectiveness comes from the motivation given to the employees through adequate training and education.

TPM is an organization-wide equipment improvement strategy, not a maintenance improvement strategy. It requires a systematic focus on eliminating equipment-related losses. It is not a program to just clean and paint equipment to look good. TPM demands and encourages the involvement of all employees, not merely involving operators in performing some elements of maintenance.

5 S — a visual workplace system — has five elements: sort, set in order, shine, standardize, and sustain. These elements are the most fundamental and often overlooked aspects in continuous improvement initiatives. 5 S is a structured program. If properly implemented, it can achieve total organization-wide cleanliness and standardization in the workplace. A well-organized workplace results in a safer, more efficient, and more productive operation. It boosts the morale of the employees, promoting a sense of pride in their work and ownership of their responsibilities.

Overall Equipment Effectiveness (OEE) is a key metric that quantifies how well an asset or a manufacturing process performs relative to its designed capacity, during the periods when it is scheduled to run. It is calculated by multiplying asset availability, performance, and quality of products it produces. Another TPM related metric is Total Equipment Effectiveness Performance (TEEP) which measures how well an organization creates value from its assets based on 24 hours per day, 365 days per year availability.

The benefits of TPM are:

- Safer workplace
- Employee empowerment and improved morale

- Increased production / output
- No or minimum defects
- No or minimum breakdowns
- No or fewer short stoppages
- Decreased waste
- Decreased O&M costs

Total Productive Maintenance thrives on the spirit of teamwork. It has a long-range outlook and may take a year or more to implement. It works not only in the manufacturing industry, but also in the service industry, construction, building maintenance, and other industrial situations.

7.7 References and Suggested Reading

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Chapter 8

PM Optimization

"Innovative practices combined with true empowerment produce phenomenal results."
Captain Michael Abrashoff, Former Commanding Officer,
USS Benfold
Author, *It's Your Ship*

After reading the chapter, the reader will be able to understand

- What is a failure?
- What are CBM /PdM and RCM?
- What it takes to implement RCM effectively
- What CBM technologies are available
- Integrating CBM into RCM methodology

8.1 Introduction

Maintenance has entered the heart of many organizational activities due to its vital role in the areas of environment preservation, productivity, quality, system reliability, regulatory compliance, safety, and profitability. With this new paradigm, new challenges and opportunities are being presented to maintenance and operations professionals. Central to maintenance is a process called Reliability Centered Maintenance, or RCM.

RCM helps determine how assets can continue to do what their users require in certain operating contexts. RCM analysis provides a structured framework for analyzing the functions and potential failures of assets such as airplanes, manufacturing lines, compressors or turbines, telecommunication systems, etc. In turn, scheduled maintenance PM plans that will provide acceptable levels of operability with acceptable levels of risk, in efficient and cost-effective manners, can be developed. RCM was developed in the commercial aviation industry in the late 1960s to optimize maintenance and operations activities.

Condition-based maintenance (CBM) is another maintenance optimizing strategy. CBM attempts to evaluate the condition of assets by performing periodic or continuous condition monitoring. The ultimate goal of CBM is to perform maintenance at a scheduled point in time when the maintenance activity is most cost-effective and before the asset loses optimum performance.

Recent developments in technologies have allowed instrumentation of assets to provide us information regarding its health. Together with better tools for analyzing condition data, today's maintenance personnel are better able to decide the right time to perform maintenance on assets. Ideally, condition-based maintenance will allow the maintenance personnel to do only the right things — minimizing spare parts cost, asset downtime, and time spent on maintenance. CBM uses real-time data to prioritize and optimize maintenance resources.

To evaluate asset condition, CBM utilizes predictive technologies such as vibration analysis, infrared, ultrasonic, corona detection, and oil analysis.

Key Terms and Definitions

Condition-Based (or Predictive) Maintenance (CBM / PdM)

Maintenance based on the actual condition (health) of assets obtained from in-place, non-invasive tests, and operating measurements.

Condition-Directed (CD) Tasks

Tasks directly aimed at detecting the onset of a failure or failure symptom. CBM technologies are used to monitor / assess the assets' health.

Corona (Partial Discharge)

The term *corona* is used as a generic name for any electrical discharges that take place in an energized electrical insulation as the result of accelerated ionization under the influence of the electric field in the insulation. It is defined as a type of localized discharge resulting from transient gaseous ionization in an insulation system when the voltage stress exceeds a critical value.

Emissivity

A fundamental property of a material, emissivity is the ratio of the rate of radiant energy emission at a given wavelength from a body with an optical smooth surface, as a consequence of its temperature only, to the corresponding rate of emission from a black body at the same temperature and wavelength.

Failure

Failure is the inability of an asset / component to meet its expected performance.

Failure Cause

The reason something went wrong.

Failure Consequences

The way in which a failure mode matters.

Failure Effect

What happens when a failure mode occurs; its consequences.

Failure-Finding (FF) Tasks

A scheduled task that seeks to determine if a hidden failure has occurred or is about to occur.

Failure Mode

An event that causes a functional failure; the manner of failure.

Failure Mode Effect and Analysis (FMEA)

A technique to examine an asset, process, or design to determine potential ways it can fail and the potential effects; and subsequently identify appropriate mitigation tasks for highest priority risks.

Ferrography

An analytical method of assessing machine health by quantifying and examining ferrous wear particles suspended in the lubricant or hydraulic fluid.

Functional Failure

A state in which an asset / system is unable to perform a specific function to a level of performance that is acceptable to its user.

Hidden Failure

A failure mode that will not become evident to the operating crew under normal circumstances.

Operating Context

The environment in which an asset is expected to operate.

P – F Interval

The interval between the point at which a potential failure becomes detectable and the point at which it degrades into a functional failure. It is also sometime called *lead time to failure*.

Potential Failure

A condition that indicates a functional failure is either about to occur or in the process of occurring.

Reliability Centered Maintenance (RCM)

A systematic and structured process to develop an efficient and effective maintenance plan for an asset to minimize the probability of failures. The process insures safety and mission compliance.

Run–to-Failure (RTF)

A management strategy (policy) that permits a specific failure mode to occur without any attempts to prevent it. A deliberate decision based on economical effectiveness.

Time-Directed (TD) Tasks

Tasks directly aimed at failure prevention and performed based on time — whether calendar-time or run-time.

Viscosity

Measurement of a fluid's resistance to flow. It is also often referred to as the structural strength of liquid. Viscosity is critical to oil film control and is a key indicator of condition related to the oil and the machine.

8.2 Understanding Failure

Figure 8.1 illustrates the period when a failure gets initiated and eventually becomes a functional failure that leads to complete asset breakdown. The asset / system performs very well in Zone A. However, somewhere in that region — due to a lack of or reduction in lubricant supply, human error, defect in material, or some other reason —a failure is initiated at the end of Zone A. This defect may be in the form of a small crack or debris stuck in the lubricant or in the valve assembly, etc. It continues to grow in Zone B, increase the asset's failure potential, though still unnoticed. At Point P at the beginning of Zone C, this defect becomes a Potential Failure. Then at Point F, at the end of Zone C, this potential failure creates a functional failure, and a function of the asset stops working.

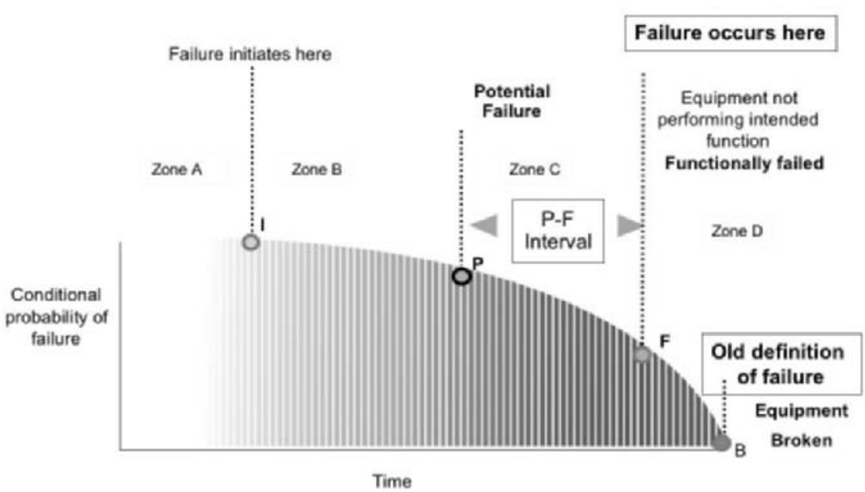

Figure 8.1 Understanding Failure

However, the asset may continue to operate at a reduced capacity or functionality. By now, there will be some visual evidence of functional failure. Eventually, at Point B, the asset completely shuts down.

The time interval between points P and F is called the P–F interval. In theory, the PM /On condition tasks interval should be less than P–F interval time so that we should be able to catch potential failures and correct them on time. However, we don't have good information about where points P or F are in time. Analysis of condition and operating data can help to estimates their (time) location. Our discussion assumes that these points are fixed in time, yet this is not the case in practice. They may vary based on the nature of the defects and the environment. Our goal is to catch any defects before they shut us down.

The best strategy is to find a defect or any abnormal condition in Zone B as soon as possible, utilizing condition-based tasks. FMEA and CBM technologies can be used to identify the sources of these defects and correct them in their early stages.

8.3 PM Optimizing Tools

PM Myths and Practices

If we were to conduct a survey among the maintenance professionals to ascertain how their PM came about or the basis of their program, the responses would probably fail to provide definitive and meaningful information. Most existing PM programs cannot be traced to their origins. For those that can, most are unlikely to make sense. The following reasons are usually the ones given for a PM program:

- **OEM Recommendations.** "The vendor / equipment supplier says ... do this." The problem with this argument is that the vendor's recommendations are mainly based on their judgment. But the vendor frequently does not know how this equipment will be used. The equipment may be designed for steady-state operations, but the real application could be highly cyclical. Moreover, vendors want us to check everything because it doesn't cost them anything.
- **Experience.** This is most common answer given to justify current PM tasks. "It has been done this way for years, so it must be good."
- **Failure Prevention.** The belief that all failures can be prevented suggests that an overhaul task can help reduce the failures — without understanding the mechanism of failure. But the overextending use of overhauls can be counterproductive. It can create

failures that were not present before the overhaul. Some items wear out with the age, but many items don't. In the absence of wear out or aging mechanisms, correcting a problem that does not exist is a waste of money.

- **Brute Force.** "More is always better." Thus, if it is physically possible to do something on equipment that appears to have PM characteristics, then it must be good thing to do. This believe leads to over-lubrication, or cleaning when equipment shouldn't even be touched, part replacement when the installed part is fine, etc.
- **Regulations.** Many products and services come under the governance of some sort of regulatory agency such as EPA, FDA, OSHA, NRC, or Public Utilities Commission's. In their well-meaning ways, these regulations can mandate PM actions that are potentially counterproductive to their objectives.

In addition, there is a risk of poor workmanship in performing PM tasks. Typically, risk may include:

- Damage to the asset receiving the PM — damage during inspection, repair, adjustment, or installation of a replacement part or material that is defective
- Incorrect reassembly or mis-installation of parts
- Infant mortality of replaced parts or material
- Damage to adjacent equipment/machinery during a PM task

Figure 8.2 summarizes published data that illustrate this risk. This data from fossil power plants examines the frequency and duration of forced

	DURATION				
Time	*<1 Week*	*1-2 Week*	*2-4 Week*	*>1 Month*	*Total*
< 1 Week	*1,705*	*35*	*16*	*16*	*1,772*
1 to 2 Weeks	*358*	*5*	*5*	*2*	*370*
2 to 3 Weeks	*258*	*8*	*0*	*1*	*267*
3 to 4 Weeks	*156*	*0*	*0*	*1*	*177*
1 to 2 Months	*324*	*12*	*2*	*2*	*340*
2 to 3 Months	*137*	*3*	*0*	*1*	*141*
>3 Months	*73*	*3*	*0*	*3*	*79*
Tota;	*3,031*	*66*	*23*	*26*	*3,146*

Figure 8.2 Frequency and Severity of Forced Outages

outages after a planned outage. As data indicates, 56% of forced outages (downtime created by a failure) occurred within one week or less after a planned outage. These statistics do not reveal how many of these forced outages were due to errors committed during the planned outages. However, there is strong evidence to conclude that the vast majority were directly due to errors caused during the planned work. Therefore, PM or repair task should only be performed when there is a strong justifiable reason to do so; then attention should be given to ensure it is performed properly.

Traditional thinking has been that the goal of preventive maintenance (PM) is to *preserve assets*. On the surface, it makes sense, but the problem is in that mindset. In fact, that thinking has been proven to be flawed at its core. The blind quest to preserve assets has produced many problems, such as being overly conservative with any maintenance actions that could cause damage due to intrusive actions, thereby increasing the chances of human error. Other flaws include both thinking that all failures are equal and performing maintenance simply because there is an opportunity to do so.

In the last few decades many initiatives have been developed in cost reduction, resource optimization, and bottom line focus of any action we take. The mentality of preserving assets quickly consumed resources, put maintenance plans behind schedule, and overwhelmed the most experienced maintenance personnel. Worse, this mentality sometimes caused maintenance actions to become totally reactive.

The development of the Reliability Centered Maintenance approach has provided a fresh perspective in which the purpose of maintenance is not to preserve assets for the sake of the assets themselves, but rather to preserve asset *functions*. At first, this might be a difficult concept to accept because it is contrary to our ingrained mindset that the sole purpose of preventive maintenance is preserving equipment operation. But in fact, in order to develop an effective maintenance strategy, we need to know what the expected output is and the functions that the asset supports —that is, the real purpose of having the asset.

RCM History and Development

Reliability Centered Maintenance is a systematic approach for developing a new PM where one does not exist, and optimizing an existing PM program. In both cases, the end result of the RCM analysis is a PM program composed of tasks that represent the most technically correct and cost-effective approach to maintaining asset/component operability. This operability in turn lends itself to improved system reliability and plant availability. Another important result of an RCM program is a documented technical basis for every PM decision.

In the late 1960s as Boeing's 747 jumbo jet was becoming a reality, all owners/operators of the aircraft were required to provide a PM program to FAA for approval in order to get certification for operation. No aircraft can be sold without this type of certification. The recognized size of the 747, about three times as many passengers as the 707 or DC-8, and its many technology advances in structure and avionics led the FAA to take the position at first that the preventive maintenance on the 747 would be very extensive. In fact, airlines thought that they may not able to operate this aircraft in a profitable manner with that requirement.

This development essentially led the commercial aircraft industry to undertake a complete re-evaluation of preventive maintenance strategy. Bill Mentzer, Tom Matteson, Stan Nowland, and Harold Heap of United Airlines led the effort. What resulted was an entirely new approach that employed a decision-tree process for ranking PM tasks that were necessary to preserve critical aircraft functions during flights. This new technique was defined and explained in Maintenance Steering Group 1 (MSG-1) for the 747 and was subsequently approved by the FAA.

With MSG-1 success, its principles were applied to other aircrafts such as DC-10, MD-80/90, and Boeing 757 / 777; and to Navy P-3 and S-3, and Air Force F-4J aircrafts under a contract with the U.S. Department of Defense (DOD). In 1975, DOD directed that the MSG concept be labeled *Reliability–Centered Maintenance* (RCM) and be applied to all major military systems. In 1978, United Airlines produced the initial RCM "bible" under DOD contract.

RCM development has been an evolutionary process. Over 40 years have passed since its inception during which RCM has become a mature process. However, industry has yet to fully embrace the RCM methodology in spite of its proven track record. In recent years, Anthony (Mac) Smith and Jack Nicholas have been leaders in creating increased RCM awareness. Examples discussed in this section are the result of work performed by Mac Smith, Glen Hinchcliffe and the author in optimizing PMs utilizing RCM methodology.

The RCM Principles

There are four principles that define and characterize RCM, and set it apart from any other PM planning process.

Principle 1: ***The primary objective of RCM is to preserve system function.*** This is one of the most important principles and perhaps the most difficult to accept because it is contrary to our ingrained notion that

PM is performed to preserve equipment operation. By addressing system function, we want to know what the expected output should be, and also that preserving that output (function) is our primary task at hand.

Principle 2: ***Identify failure modes that can defeat the functions.*** Because the primary objective is to preserve system function, the loss of function is the next item of consideration. Functional failures come in many sizes and shapes; they are not always as simple as, "we have it or we don't." For example, the loss of fluid boundary integrity in a pumping system illustrates this point. A system loss of fluid can be 1) a very minor leak that may be qualitatively defined as a drip; 2) a fluid loss that can be defined as a design basis leak — that is, any loss beyond a certain flow value will produce a negative effect on system function but not necessarily total loss; or 3) a total loss of boundary integrity, which can be defined as a catastrophic loss of fluid and loss of function. In this example, a single function —preserve fluid integrity — led to three functional failures. The key point of Principle 2 is to identify the specific failure modes in specific component that can potentially produce those unwanted functional failures.

Principle 3: ***Prioritize function needs (failures modes).*** All functions are not equally important. A systematic approach is taken to prioritize all functional failures and failure modes using a priority assignment rationale.

Principle 4: ***Select applicable and effective tasks.*** Each potential PM task must be judged as being applicable and effective. Applicable means that if the task is performed, it will accomplish one of three reasons of doing PM:

1. Prevent
2. Mitigate failure
3. Detect onset of a failure or discover a hidden failure

Effective means that we are sure that this task will be useful and we are willing to spend resources to do it.

In addition, RCM recognizes the following:

- **Design Limitations.** The objective of RCM is to maintain the *inherent* reliability of system function. A maintenance program can only maintain the level of reliability inherent in the system design; no amount of maintenance can overcome poor design. This makes it imperative that maintenance knowledge be fed back to designers to improve the next design. RCM recognizes that there is a difference between perceived design life (what the designer thinks the life of the system is) and actual design life. RCM explores this through the Age Exploration (AE) process.

- **RCM Is Driven by Safety First, then Economics.** Safety must be maintained at any cost; it always comes first in any maintenance task. Hence, the cost of maintaining safe working conditions is not calculated as a cost of RCM. Once safety on the job is ensured, RCM assigns costs to all other activities.

Elements of RCM

According to the SAE JA1011 standard, which describes the minimum criteria that a process must comply with to be called "RCM," a Reliability Centered Maintenance Process answers the following seven essential questions:

1. What are the functions and associated desired standards of per formance of the asset in its present operating context (functions)?
2. In what ways can the asset fail to fulfill its functions (functional failures)?
3. What causes each functional failure (failure modes)?
4. What happens when each failure occurs (failure effects)?
5. In what way does each failure matter (failure consequences)?
6. What should be done to predict or prevent each failure (proactive tasks and task intervals)?
7. What should be done if a suitable proactive task cannot be found (default actions)?

Unlike some other maintenance planning approaches, RCM results in all of the following tangible actionable options:

- Maintenance task schedules which can include:
  - Time Directed (TD) tasks, (Calendar/run time based PMs)
  - Condition Directed (CD) tasks, (CBM/PdM tasks)
  - Failure Finding (FF) tasks (operator supported tasks)
  - Run-to-Failure (RTF) tasks (economical decision based)
- Revised operating procedures for the operators of the assets, which might include service-type tasks such as changing filters, taking oil samples, and recording operating parameters
- A list of recommended changes to the design of the asset that would be needed if a desired performance is to be achieved.

RCM shifts the emphasis of maintenance from the idea that all failures are bad and must be prevented, to a broad understanding of the purpose of maintenance. It seeks the most effective strategy that focuses on the performance of the organization. It might include not doing something about a failure or letting failures happen. The RCM approach encourages us to think of more encompassing ways of managing failures.

RCM Analysis Process

Although RCM has a great deal of variation in its application, most procedures include some or all of the following nine steps:

1. System selection and information collection
2. System boundary definition
3. System description and functional block diagram
4. System functions and functional failures
5. Failure mode and effects analysis (FMEA)
6. Logic (decision) tree analysis (LTA)
7. Selection of maintenance tasks
8. Task packaging and implementation
9. Making the program a living one — continuous improvements

Step 1: System Selection and information Collection The purpose of step 1 is to assure that the RCM team has sufficiently evaluated their area to know which systems are the problems or so-called *bad actors*. The team can use Pareto analysis (80/20 rule) to determine the list of problems, using criteria of highest total maintenance costs (CM+PM), downtime hours, and number of corrective actions. Identifying these systems defines the dimensions of the RCM effort that will provide the greatest Return-on–Investment. Figure 8.3 lists a plant's asset data — failure frequency, downtime, and maintenance costs — to help us decide which assets are the right candidates for RCM analysis. The first few assets listed in Figure 8.3 are good candidates for RCM effort.

Selection of RCM team members is a key element in executing a successful RCM program. The team should include the following:

- System operator (craft)
- System maintainer (craft – mechanical / electrical / controls)
- Operations / Production engineer
- Systems / Maintenance engineer (mechanical / electrical)
- CBM/PdM specialist or technician
- Facilitator

Plant Assets	# Of Failures	Downtime Hours	CM Cost	PM Cost	Total Maintenance Cost
Air Compressor #1	28	68.40	$2,502	$1,707	$4,207
Crane - 150 Ton	24	74.87	$2,728	$1,705	$4,433
NC Machine #3	20	55.20	$2,040	$1,285	$3,325
Grinder #2	7	16.00	$668	$1,285	$1,953
Assembly Machine Ctr #2	5	12.60	$549	$1,285	$1,834
Hydraulic Sys # XX	4	21.25	$852	$865	$1,717
Punch Press #4	3	8.00	$388	$865	$1,253
Fork Lift #2	2	7.80	$381	$865	$1,246
Lathe #4	2	9.50	$441	$865	$1,306
Hydraulic Sys # YY	2	12.60	$549	$865	$1,414
NC Machine #1	1	8.40	$402	$865	$1,267
Lathe #5	1	4.25	$257	$865	$1,122
Drilling Machine #7	1	2.50	$196	$865	$1,061
Total	100	301	$11,952	$14,185	$26,137

Figure 8.3 Plant Failure and Cost Data by Assets

Facilitators are recommended to support RCM effort. They ensure that the RCM analysis is carried out at the proper level, no important items are overlooked, and the results of the analysis are properly recorded. Facilitators also manage issues among the team members, helping them reach consensus in an orderly fashion, retaining the members' commitment, and keeping them engaged.

A secondary objective of Step 1 is to collect information that will be required by the team as they perform the system analysis. This information includes schematics, piping and instrumentation diagrams (P&ID), vendor manuals, specification and system descriptions, operating instructions, and maintenance history.

Step 2: System Boundary Definition After a system has been selected, the next step is to define its boundaries —understanding the system as a whole and its functional sub-systems. This step assures that there are no overlaps or gaps between adjacent systems. We need to have a clear record for future reference on exactly what was in system. In addition, we must specify the boundaries in precise terms; a key portion of analysis depends on defining exactly what is crossing the boundaries, both "incoming – IN" and "outgoing – OUT" interfaces respectively.

An example of a system boundary is shown in Figure 8.4.

RCM - System Analysis

Step 2:	System Boundary	Plant ID # 000456
Information:	Boundary Overview	System ID # V - 456-xx123
Plant #:	V-HPA	
System:	X3 Pumping System	
Team:	Ed I, Brian S, Brown L, Ronnie S, Mike H, Glen H (facilatator)	
		Date: 2/20/02

Major asset (level 2) included:		
	Induction Motor GE - 6000 HP	ID # X3-000112
	IR - 2 State Centrifugal Compressor	ID # X3-000113
	Coupling	ID # X3-000221
	Lub Oil Pump	ID # X3-000222
	Lub Oil Cooler	ID # X3-000223
	Inlet Air Filter	ID # X3-000224
	Valves # V1, V2, V3, V4	ID # X3-000331-34
Primary physical boundary		
	Air from atmosphere enter into Air Filter	
	38 psign - 100 F air exit at outlet of V4	
Caveate:	Electric supply - breakers, starter, cables etc. not included	

Figure 8.4 System Boundary Definition

Step 3: System Description and Functional Block Diagram Step 3 requires identifying and documenting the essential details of the system. It includes the following information:

- System description
- Functional block diagram
- IN / OUT interfaces
- System work breakdown structure
- Equipment /component history

A well-documented system description will record an accurate baseline definition of the system as it existed at the time of the RCM analysis. Various design and operational changes can occur over time. Therefore, the system must be baselined to identify where PM task revision might be required in the future. Frequently it has been found that team members and analysts may have only a superficial knowledge of the system. Recording a detailed system functional description narrative will assure that the team has a comprehensive review of the system.

In addition, documenting the following information can be helpful in analyzing the data later on:

- **Redundancy Feature:** Equipment / component redundancy, alternate mode operations, design margins and operators work-around capabilities
- **Protection Features:** A list of devices that are intended to prevent personnel injury or secondary system damages when an unexpected component failure occurs; it may include items such as inhibit or permissive signals, alarms, logic, and isolation
- **Key Control Features:** An overview of how the system is controlled; also briefly highlighting features such as automatic vs. manual, central vs. local, and various combinations of the above as they may apply

The next item in Step 3 is to develop a Functional Block Diagram (FBD), which is a top-level representation of the major interfaces between a selected system and adjacent systems. Figure 8.5 illustrates an FBD with functional interfaces including sub-systems.

In an actual team setting, it has been found to be desirable to have a discussion first regarding various possibilities that should be considered in creating functional sub-systems. When FBD is finalized, it will show a decision on the use of functional subsystems as well as the final representation of the IN / OUT interfaces.

Listing all components as part of System Work Breakdown Structure (SWBS) is very desirable. The SWBS is the compilation of the line items list for the system. SWBS is a system hierarchy listing parent –child relationships. In most cases, the SWBS should be what's in the CMMS for the system being analyzed. In older plants, where the reference sources could be out of date, the RCM team should perform a system walk down to assure accuracy in final SWBS. This practice is a good one, even if the system is well documented, to help the team familiarize itself with the system.

The last item in Step 3 is to get system history. It will be beneficial for the analysis team to have a history of the past 2–4 years of component and system failure events. This data should come from corrective maintenance reports or from the CMMS system. Unfortunately, it is not uncommon to find a scarcity of useful failure event information. In many plants, the history kept is of very poor quality. Most of the time, the repair history will simply state "Repaired pump" or "Fixed pump," etc.. Improving data quality is a challenge for many organizations.

RCM - System Analysis

Step 3:	System Functional Block Diagram (FBD)	Plant ID # 000456
Information:	Boundary Overview	System ID # V - 456-xx123
Plant #:	V-HPA	
System:	X3 Pumping System	
Team:	Ed I, Brian S, Brown L, Ronnie S, Mike H, Glen H (facilatator)	
		Date: 2/20/02

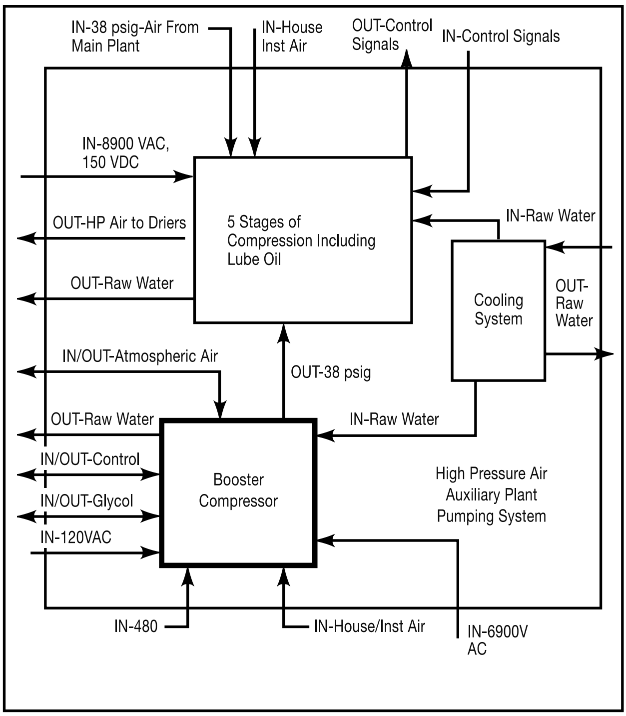

Figure 8.5 Functional Block Diagram.

Step 4: System Functions and Functional Failures Because the ultimate goal of an RCM is "to preserve system function," it is incumbent upon the RCM team to define a complete list of system functions and functional failures. Therefore, in Step 4, system functions and functional failures are documented.

The function statement should describe what the system does — its functions. For example, a correct function might be "Maintain a flow of 1000 GPM at header 25," but not "provide a 1000 GPM centrifugal Pump for discharge at header 25." Another example would be "maintain lube oil temperature ≤ 110 ^{0}F. In theory, we should be able to stand outside of a selected system boundary, with no knowledge of the SWBS for the system, and define the functions by simply what is leaving the system (OUT interfaces).

The function definition should be as quantitative as possible. For example, a function should not be defined as "To produce as many units as possible," but rather "To produce a target of 25 units with a minimum of 22 units in an 8-hour shift." It becomes difficult to decide on maintenance strategies or to hold maintenance workers accountable for not meeting maintenance goals when those goals are not defined precisely.

The next step is to specify how much of each function can be lost, i.e., functional failures. Most functions have more than one loss condition if we have done a good job with the system description. For example, the loss condition can range from total loss and varying levels of partial loss

RCM - System Analysis

Step 4:	Functions/Functional Failures	Plant ID # 000456
Information:	Functional Failure Description	System ID # V - 456-xx123
Plant #:	V-HPA	
System:	X3 Pumping System	
Team:	Ed I, Brian S, Brown L, Ronnie S, Mike H, Glen H (facilatator)	
		Date: 3/12/02

Function #	FF#	Function/Functional Failure Description
1.0		Supply compressed atmospheric air at 38 PSIG and 6050 CFM to 93 A/B compressors at normal operating conditions
	1.1	No Air Supplied
	1.2	Incorrect Air Pressure
	1.3	Air supplied at off-normal operating conditions
2.0		Provide filtered lubricaitons at required temperature and pressure
	2.1	Loss of lubrication
	2.2	Lubrication at improper temperature, pressure, and cleanliness
3.0		Remove heat of compression
	3.1	Can not remove heat of compression
	3.2	Incorrect removal of heat of compression (high or low)
4.0		Provide filtered atmospheric, instrument and seal air at required conditions
	4.1	No filtered air
	4.2	Air at incorrect conditions (high or low pressure, dirty)
5.0		Provide appropriate signals (controlling, alarming, status, and protection)
	5.1	No signals provided
	5.2	False signals
6.0		Maintain boundary integrity
	6.1	Loss of boundary integrity

Figure 8.6 Functions / Functional Failures.

which have different levels of plant consequences (and thus priority) to failure to start on demand, etc. The ultimate objective of an RCM analysis is to prevent these functional failures and thereby preserve function. In Step 7, this objective will led to the selection of preventive maintenance tasks that will successfully avoid the really serious functional failures.

Step 5: Failure Mode and Effects Analysis (FMEA) Step 5, Failure Mode and Effects Analysis, is the heart of the RCM process. FMEA has been used traditionally to improve system design and is now being used effectively for failure analysis that is critical to preserve system function.

By developing the functional failure – equipment matrix, Step 5 considers for the first time the connection between function and hardware. This matrix lists functional failures from Step 4 as the horizontal elements and the SWBS from Step 3 as the vertical elements. The team's job at this point is to ascertain from experience whether each intersection between the components and functional failure contains the making of some malfunction that could lead to a functional failure. The team completes the matrix by considering each component's status against all functional failures, moving vertically down the component list one at a time. After the entire

RCM - System Analysis

Step 5:	Function Mode and Effects Analysis	Plant ID # 000456
Information:	Functional Failure	System ID # V - 456-xx123
Plant #:	V-HPA	
System:	X3 Pumping System	
Team:	Ed I, Brian S, Brown L, Ronnie S, Mike H, Glen H (facilitator)	
		Date: 3/22/02

							Failure Effect			
FF#	Comp #	Comp. Description	FM#	Failure Mode	FC#	Failure Cause	Local	System	Plant	LTA
1.1	01	6.9 kV Motor	1.01	Bearing seizures	1.1.1	1) Oil contamination 2) Lack of lubrication	Can't supply air to C93A/B	Can't supply air to C93A/B	Loss of high pressure air (HPA)	YES
1.1	01	6.9 kV Motor	1.02	Bearing wear	1.2.1	1) Normal use 2) Oil contamination	Elevated bearing temperature and vibration	Worst cast: Can't supply air to C93A/B	Loss of high pressure air (HPA)	YES
1.1	01	6.9 kV Motor	1.03	Windings shorted or open (insulation degradation)	1.3.1	1) Aging and contamination 2) End winding corona	Motor won't run	Can't supply air to C93A/B	Loss of high pressure air (HPA)	YES
1.1	01	6.9 kV Motor	1.04	Loose or cracked surge ring and end turn blocking and ties	1.4.1	Vibration and heat	Elevated winding temperatures that lead to failure	Worst cast: Can't supply air to C93A/B	Loss of high pressure air (HPA)	YES
1.1	01	6.9 kV Motor	1.05	RTD fails open	1.5.1	Internal failure	Loss of motor temperature indication	None	None	NO
1.1	01	6.9 kV Motor	1.06	Air filter clogging	1.6.1	Dirt	Motor runs hot	None	None	NO

Figure 8.7 Example of FMEA

matrix has been completed, it will produce a pattern of Xs that essentially constitutes a road map to guide to proceed for detailed analysis.

The next step in this process is to perform FMEA, considering each component and functional failures as shown in Figure 8.7. FMEA addresses the second RCM principle, to "determine the specific component failures that could lead to one or more of the functional failures." These are the failures which defeat functions and become the focus of the team's attention.

In reviewing failure modes, teams can use the following guidelines in accepting, rejecting, or putting aside for later considerations:

- **Probable Failure Mode.** Could this failure mode occur at least once in the life of the equipment / plant? If yes, it is retained. If no, it is considered a rare event and is dropped out from further consideration.
- **Implausible Failure Mode.** Does this failure mode defy the natural laws of physics — is it one that just could not ever happen? There are usually few, if any, hypothesized failure modes in this category. But if one arises, label it as "Implausible" and drop it from further consideration.
- **Maintainable Failure Mode.** Certain failure modes clearly can pass the above two tests, but in the practical sense would never be a condition where a preventive action would be feasible. Doing preventive maintenance on a printed circuit board full of IC chips is one example where the practical maintenance approach is to replace it when (and if) it fails. Such failure modes usually are dropped out too.
- **Human Error Causes.** If the only way this failure mode could happen is the result of an unfortunate (but likely) human error, we note as such for the record. But we drop it from further consideration because we really can not schedule a preventive action to preclude such random and uncontrollable occurrences. If the hypothesized human error problem is important, however, we could submit this condition to an item of interest (IOI) for later evaluation of other forms of corrective or mitigating action.

For each failure mode retained for analysis, the team then decides on its one or two most likely failure causes. A failure cause is, by definition, a 1–3 word description of *why* the failure occurred. We limit our judgments to *root* causes. If the failure mode can occur only due to another previous failure somewhere in the system or plant, then this is considered a consequential cause.

The establishment of the failure mode list for each X intersection is perhaps the single most important part of the RCM process; it is these failure modes that will drive our PM decisions and resource allocations if they pass the priority tests that are designated in the analyses to follow.

Each failure mode retained is now evaluated as to its local effect. What can it do to the component; what can it do to the system functions; how can it impact the system / plant output? If safety issues are raised, they too can become part of the recorded effect. In the failure effects analysis, assume a single failure scenario. Also allow all facets of redundancy to be employed in arriving at statements of failure effect. Thus, many single failure modes can have no effect at the plant or system level, in which case, designate the as low priority and do not pass them to Step 6, Logic Tree Analysis. If there is either a system or plant effect, the failure mode is passed on to Step 6 for further priority evaluation. Those failure modes considered as low priority here are assigned as candidates for run-to-failure (RTF) and are given a second review in Step 7 for final RTF decision.

Step 6: Logic (Decision) Tree Analysis (LTA) Any component failure mode that resulted in a yes in Step 5, is now processed to satisfy the third principal, to "prioritize the failure modes," In Step 6, because of the fact that not all failures are equally important, we need to screen our information further to focus on what really counts.

The Logic Tree shown in Figure 6.8 poses three simple questions that require either a Yes or No answer. The result is that each failure mode will ultimately be assigned an importance designator that will constitute a natural ordering of the priority that we should address in allocating our resources. The following coding is used to label the failure modes:

A — Top priority item
B — Second and next significant item
C — A low priority item and may likely be a non-PM item to consider
D — RTF item

The three questions are:

1. Under normal conditions, do the operations know that something has occurred?

   Question 1 looks at operator knowledge that something is not normal, given the occurrence of the failure mode. It is not necessary

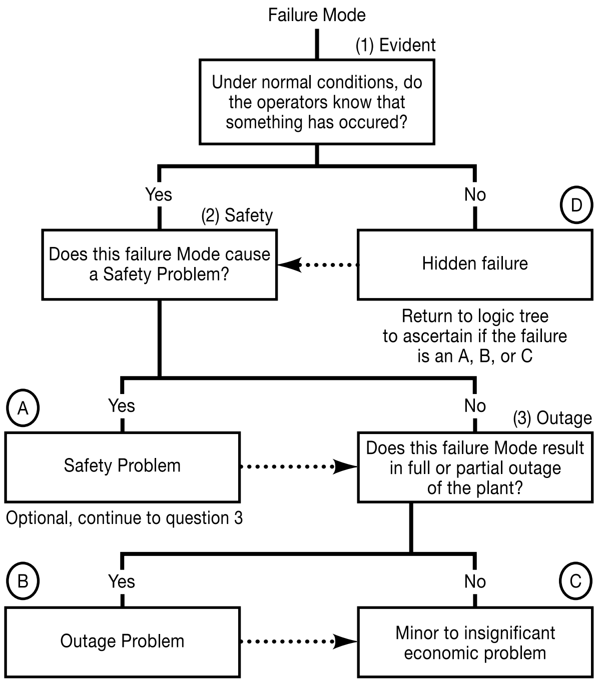

Figure 8.8 Logic Tree Analysis Structure.

that operators know exactly what failure mode has occurred. They may pinpoint the exact failure instantly. If they sense an abnormality, they will look to find out what is wrong. This mode is an evident failure mode. If the operators have no clue whatsoever as to the occurrence of the abnormality, the failure mode is hidden, and receives the label "D" at this point.

2. Does this failure mode cause a safety problem?

   The failure mode is then carried to Question 2 regarding possible safety or environment issues. An answer of *Yes* to Question 1 picks up an "A" label on the failure mode, a rating which raises the failure mode to the highest importance level in the LTA.

3. Does this failure mode result in full or partial outage of the plant?

   Finally, Question 3 inquires as to whether the failure mode could lead to a plant outage (or production downtime). An answer of *Yes* here results in a "B" label; *No*, by default, results in a "C" label. A "C" designates the failure mode as one of little functional significance.

Thus, every failure mode passed to Step 6 receives one of the following labels or categories: A, B, C, D, or any combination of these. Any failure mode that contains an "A" in its label is a top priority item; a "B" is the second and next significant priority item; a "C" is essentially a low priority item that, in the very practical sense, is probably a non-issue in allocating preventive maintenance resources. All C and D/C failure modes are good candidates for RTF. Primary attention will be placed on the A and B labels, which are addressed in Step 7.

Step 7: Selection of Maintenance (PM) Tasks The fourth RCM principle, "select applicable and effective PM tasks for the high priority failure modes," is addressed in this step.

In Step 7, all team knowledge is applied to determine the most applicable and cost effective tasks that will eliminate, mitigate, or warn us of the failure modes and causes that we assigned to each component or piece of equipment in Step 5. The team revisits those failure modes they initially believed did not impact the functioning of system, and re-evaluates them. Finally, the team compares the new PM program to the old one, seeing where the program has been improved and optimized. Step 7 is comprised of three steps that are discussed in this section:

- Task selection
- Sanity check
- Task comparison

In task selection, the following questions are addressed:

- Is the age reliability relationship for this failure known? If yes,
- Are there any applicable Time directed (TD) tasks? If yes,
- Specify those tasks.
- Are there any Condition Directed (CD) tasks? If yes,
  - Specify those tasks.
- Is there a "D" category of failure modes? If yes,
  - Are there any applicable Failure Finding (FF) Tasks? If, yes
  - Specify those tasks.
- Can any of these tasks be ineffective? If no,
  - Finalize tasks above as TD, CD, and FF tasks.
- If any tasks may not be effective, then
  - Can design modifications eliminate failure mode or effect?
- If yes, request design modifications.

Task Selection is a key item to be discussed in this Step. It is very important that the Team members put their past biases aside at this juncture and develop a creative and free-flowing thought process to put forth the best possible ideas for candidate PM tasks — even if some of their suggestions may sound a bit off-the-wall at first blush. It might also be useful to get the help of predictive maintenance specialists if they are not part of the team.

A final aspect of the Task Selection process is to revisit the failure modes that are designated as RTF candidates. This is part of the Sanity Check, to insure all task selections are appropriate. We need to examine other non-function related consequences that could cause us to reverse the RTF decision for reasons such as high cost, regulatory difficulties and violations, the likelihood of secondary failure damage, warranty and insurance factors, or hidden failure conditions. The team can elect to drop the RTF decision in favor of a PM task if they believe that the potential consequences of the failure mode are severe.

The last item in the RCM system analysis process before proceeding to PM task implementation is Task Comparison. Now the team lays out what they have recommended for an RCM-based program versus the current PM program. This is the first time in the entire process that the team will deliberately examine the current PM task structure in detail.

The difficulty in performing Task Comparison stems from the fact that the RCM-based PM tasks were developed at the failure mode level of analysis detail whereas the current PM tasks were identified at the component level. Hence, analysts must use their experience and judgment to fit the current PM tasks into a structure that is comparing PM programs at the failure mode level. This can be somewhat difficult at times and may require careful review.

Task Comparison has many uses, but two are most important:

1. Task comparison can be used as an excellent summary for management review and approval to implement the RCM recommendations. It also serves as a nicely-packaged input for task implementation.
2. A full RCM analysis is now available to show the step-by-step traceability of how and why a given PM task was developed and selected.

Step 8: Task Packaging and Implementation Step 8, task packaging and implementation, is a crucial step for realizing the benefits of RCM analysis. Usually this step is very difficult to accomplish successfully. In fact, the majority of RCM failures happen during this step and analysis results are put aside on the shelf. However, if team members have been selected from all critical areas and they have been participating diligently, implementation will go smoothly and will be successful.

The final implementation action is to write task procedures that communicate analysis results to the actionable instructions to the operating and maintenance teams including CBM/PdM technicians. If the work is multi-disciplined (multi-craft skills), it may require writing separate instructions for each craft group, depending upon union contract requirements. However, the coordination between the craft should be part of each instruction. Nevertheless, it is always beneficial and effective to have multi-skill crew to handle multi-disciplined work. In most cases, these instructions will be kept in the CMMS and will be issued per established schedule or based on CBM data. The following list of items can be part of good PM work instructions: (See example on facing page)

Step 9: Making the Program a Living One — Continuous Improvements

RCM execution is not a one-time event. It's a journey. RCM is a paradigm shift in how maintenance is perceived and executed. An RCM-based PM program needs to be reviewed and updated on a continuous basis. A living RCM program consists of:

- Validation of existing program — maintenance decisions made are appropriate
- Making adjustments in PM program if needed

A living RCM program assures continual improvement and cost-effective operation and maintenance in the organization. We also need to establish some effective metrics to know where the program stands.

Other RCM Processes

There are many derivatives of RCM such as RCM++, RCM cost, RCM turbo, RCM backfit, RCM streamline, VRCM, Abbreviated, and Experience Based. All of these derivatives help perform RCM cost effectively. Most of them take some short cuts —cutting some steps, considering only a limited number of failure modes, or automating the process using software to reduce the time taken to complete the analysis. In addition, RCM software programs are also available from JMS software-worksaver, Isograph, ReliaSoft, Relex, and others. These programs can help to reduce the time taken to perform an RCM analysis in much shorter time. They all use a standardized RCM process.

PM Work Instruction Example

1.	Work Instruction Title	Compressor #xx — area XY
2.	Task Instructions #	PM XXXXX
3.	Task Interval	6 Month / 1000 hours of operations
4.	Priority	Low, medium, high, or X-based on organization's priority scheme
5.	Estimated Hours with Skill	Mech. — 20, Elect — 10, Total = 30
6.	Actual Hours	Mech. — 18, Elect – 10, Labor – 4, Total = 34 (Inputted after the job has been completed)
7.	Component Name and ID #	
8.	Contact #	Planner #; Systems Engineer #
9.	Special safety instructions	Lock out / Tag Out details and clearance permits
10.	Special Tools requirements	
11.	Material Handling support requirements	
12.	Task Objectives	
13.	Task detailed — steps	
14.	Spare / parts required	
15.	As found condition list	
16.	Work performed	
17	Post maintenance t est measurement data	
18.	Other observations —	Notes: Could the effectiveness of this PM be improved? Yes / No, and how?

RCM Benefits

- **Reliability.** The primary goal of RCM is to improve asset reliability. This improvement comes through constant reappraisal of the existing maintenance program and improved communication between maintenance supervisors and managers, operations personnel, maintenance mechanics, planners, designers, and equipment manufacturers. This improved communication creates a feedback loop from the maintenance craft in the field all the way to the equipment manufacturers.

- **Cost.** Due to the initial investment required to obtain the technological tools, training, and equipment condition baselines, a new RCM program typically results in a short-term increase in maintenance costs. The increase is relatively short-lived. The cost of reactive maintenance decreases as failures are prevented and preventive maintenance tasks are replaced by condition monitoring. The net effect is a reduction of reactive maintenance and a reduction in total maintenance costs.
- **Documentation.** One of the key benefits of an RCM analysis is understanding and documentation of operations and maintenance key features, failures modes, basis of PM tasks, related drawings and manuals, etc. This documentation can be good training material for new O&M personnel.
- **Equipment/Parts Replacement.** Another benefit of RCM is that it obtains the maximum use from the equipment or system. With RCM, equipment replacement is based on equipment condition, not on the calendar. This condition based approach to maintenance extends the life of the facility and its equipment.
- **Efficiency/Productivity.** Safety is the primary concern of RCM. The second most important concern is cost effectiveness, which takes into consideration the priority or mission criticality and then matches a level of cost appropriate to that priority. The flexibility of the RCM approach to maintenance ensures that the proper type of maintenance is performed when it is needed. Maintenance that is not cost effective is identified and not performed.

In summary, the multi-faceted RCM approach promotes the most efficient use of resources. The equipment is maintained as required by its characteristics and the consequences of its failures.

Impact of RCM on a Facility's Life Cycle

RCM must be a consideration throughout the life cycle of a facility if it is to achieve maximum effectiveness. The four major phases of a facility's life cycle are:

1. Planning (Concept)
2. Design and Build

3. Operations and Maintenance
4. Disposal

It has been documented in many studies that 85% or more a facility's life cycle cost is fixed during planning, design and build phase. The subsequent phases fix the remaining 15% or so of the life-cycle cost. Thus, the decision to institute RCM at a facility, including condition monitoring, will have a major impact on the life-cycle cost of the facility. This decision is best made during the planning and design phase. As RCM decisions are made later in the life cycle, it becomes more difficult to achieve the maximum possible benefit from the RCM program.

Although maintenance is a relatively small portion of the overall life-cycle cost, a balanced RCM program is still capable of achieving savings of 10–30% in a facility's annual maintenance budget during the O&M phase.

CBM / PdM Technologies

The start of Condition-Based Maintenance (CBM) — also called Predictive Maintenance or PdM — may have been when a mechanic first put his ear to the handle of a screwdriver, touched the other end to a machine, and pronounced that it sounded like a bearing was going bad. We have come a long way since then with a variety of technologies for analyzing what's going on inside the asset. However, the need for a knowledgeable, experienced person to use the technology has not changed. Today, as in the beginning, successful predictive maintenance is a combination of man and technology.

Recent advances in technology have made CBM a reality — the ready availability of inexpensive computing power to gather, store, and analyze the data that makes CBM possible. By some counts, there are more than 30 technologies being used for condition-based maintenance. Others might argue that many of these are simply variations of each other. This section discusses some of the most-used CBM/PdM technologies.

Any condition-based maintenance program can be characterized by a combination of three phases:

- Surveillance — monitoring machinery condition to detect incipient problems
- Diagnosis / Prognosis — isolating the cause of the problem and developing a corrective action plan
- Remedy — performing corrective action

Consistent, accurate data gathering is essential to all three phases.

Analysis of data is where the knowledge and experience of maintenance personnel becomes most important. It normally requires extensive training not only in the analysis techniques, but also in the use of the particular hardware and software employed.

Condition Monitoring and Data Collection

Condition monitoring uses primarily nonintrusive testing techniques, visual inspections, and performance data to assess machinery condition. It replaces arbitrarily timed maintenance tasks with maintenance scheduled only when warranted by asset condition. Continuing analysis of the asset condition allows planning and scheduling of maintenance or repairs in advance of catastrophic or functional failure.

The data collected is used in one of the following ways to determine the condition of the asset and to identify the precursors of a failure:

- **Trend Analysis.** This method reviews data to see if an asset is on an obvious and immediate "downward slide" toward failure. It includes recognizing the changes in data as compared to earlier data or baseline data on similar assets.
- **Pattern Recognition.** This method reviews data to recognize any causal relationships between certain events and asset failure. For example, we might notice that after asset X is used in a certain production run, component aX fails due to stresses unique to that run. The method identifies deviations from established patterns.
- **Correlation analysis.** This approach compares data from multiple sources, related technologies, or different analysts.
- **Tests against Limits and Ranges.** These tests set alarm limits and see if they are exceeded.
- **Statistical Process Analysis.** This analysis uses statistical techniques to identify deviations from the norm.

If published failure data on a certain asset or component exists, then we can compare failure data collected onsite with the published data to verify or disprove that published data.

Many CBM technologies are available to assess the condition of an asset or system. Sometimes several technologies are used together to provide a full and accurate picture of the asset condition. For example, to obtain the total picture of a cooling water system, a CBM effort needs to collect the following data:

- **Flow Rates.** Water flow is measured using precision, nonintrusive flow detectors.
- **Temperature.** Differential temperature is measured to determine heat transfer coefficients and to indicate possible tube fouling.
- **Pressure.** Differential pressures across the pump and piping are measured to determine pump performance and to determine the condition of the tubes.
- **Electrical.** Motor power consumption is used to assess the condition of the motor.
- **Vibration.** Vibration monitoring is used to assess the condition of rotating equipment such as pumps and motors. Additionally, structural problems can be identified through resonance and model testing.
- **Ultrasonic Testing.** Pipe wall thickness is measured to determine erosion and corrosion degradation and also leaking pipes.
- **Airborne Ultrasonic.** Airborne ultrasonic indicates air leaking from control system piping and pumps.
- **Lubricant Analysis.** Oil condition and wear particle analysis are used to identify problems with the lubricant, and to correlate those problems with vibration when wear particle concentrations exceed pre-established limits.
- **Infrared Thermography.** Thermography scans motor control system and electrical distribution junction boxes for high-temperature conditions. High temperature is indicative of loose connections, shorts, or failing conductor insulation. Piping insulation is checked for porosities. High temperatures are indicative of failed/failing areas in the pipe insulation.
- **Data Collection**
  Asset condition data is collected basically in two ways:

1. Spot readings — route based with hand-held instruments
2. Permanently installed data acquisition equipment for continuous data collection — ONLINE

Generally, taking spot readings provides sufficient information for making informed decisions regarding maintenance of assets. The degradation of facility assets is usually not so rapid as to require the "up to the second" reporting that a permanent data acquisition system produces. Usually, the maintenance technician or a CMMS can keep a log of these spot readings and develop trends from these logs.

Permanent condition monitoring equipment is expensive to install, and the data bases created cost money to analyze and maintain. Typically, permanent data collection systems are installed only on critical and expensive assets and systems used in production processes. If they go down, it costs the facility "money by the minute" when it is not operating.

A variety of technologies are available to assess the condition of systems and equipment, and to determine the most effective time for scheduled maintenance. Some of the key technologies covering the basic theory of how the technology operates, the purpose of applying the technology, and acceptable applications are discussed in this section.

Vibration Analysis

Vibration monitoring might be considered the "grandfather" of condition / predictive maintenance, and it provides the foundation for most facilities' CBM programs.

Vibration usually indicates trouble in the machine. Machine and structures vibrate in response to one or more pulsating forces that may be due to unbalance, misalignment, etc. The magnitude of vibration is dependent on the force and properties of the system, both of which may depend on speed.

There are four fundamental characteristics of vibration: frequency, period, amplitude, and phase. *Frequency* is the number of cycles per unit time and is expressed in the number cycles per minute (CPM) or cycles per second (Hz). The *period* is the time required to complete one cycle of vibration. Therefore, it is reciprocal of frequency. The operating speed of an asset or machine is usually expressed in revolution per minute (RPM). The *amplitude* is the maximum value of vibration at a given location of the machine. *Phase* is the time relationship between vibrations of the same frequency and is measured in degrees.

The three key measures used to evaluate the magnitude of vibrations are:

- Displacement
- Velocity
- Acceleration

The units and descriptions of these measures are shown in Figure 8.9.

Displacement measurement is the dominant at low frequency and is caused by stresses in flexible members of the machine. Usually it is expressed in mils, peak-to-peak because the machine motions are often non harmonic and therefore yield positive and negative peaks. Displacement is a good measure for low frequency vibration, usually less

Measure	Units	Description
Displacement	mils peak-to-peak (p-p)	motion of machine, structure or rotor - relates to stress
Velocity	in / sec	rate of motion, relates to usually component fatigue
Acceleration	in/2 sec or g's	relates to forces present in components
1 mil = 0.001 inch and 1g = 386.1 inches/sec		

Figure 8.9 Vibration measures

than 20 Hz. Velocity is the time-rate change of displacement. It is dependent upon both displacement and frequency. It is related to fatigue characteristics of the machine. The greater the displacement and the frequency of vibration, the greater is the severity of machine vibration at the measured location. Velocity is used to evaluate machine condition in the frequency range of 10–1,000 Hz. The acceleration is the dominant measure at higher frequencies that exceed 1,000 Hz. Acceleration is proportional to the force on machine components such as gears and couplings.

Velocity and accelerations are calculated by the following formulas:

$$\text{Velocity (V)} = 2\pi f d$$

$$\text{Acceleration} = 2\pi f V = (2\pi f)^2 d,$$

where

f = frequency in cycles per second and d = peak displacement

Monitoring the vibration of facility machinery can provide direct correlation between the mechanical condition and recorded vibration data of each machine in the plant. This data can identify specific degrading machine components or the failure mode of plant assets before serious damage occurs.

Vibration monitoring and trending works on the premise that every machine has a naturally correct vibration signature. This signature can be measured when the machine is in good working order, and subsequent measurements can be compared with what is considered the norm. As the components wears or ages, the vibration spectra change. Analyzing the changes identifies components that require further watching, repair, or replacement.

With a few exceptions, mechanical troubles in a machine cause vibration. The most common problems that produce vibration are:

- Unbalance of rotating parts
- Misalignment of couplings and bearings
- Bent shafts
- Worn, eccentric, or damaged parts
- Bad drive belts and chains
- Damaged / bad bearings
- Looseness
- Rubbing
- Aerodynamic and other forces

Under conditions of dynamic stress, displacement alone may be a better indication of severity, especially when the asset components exhibit the property of brittleness — the tendency to break or snap when stressed beyond a given limit. Consider a slowly rotating machine that operates at 60 RPM, and that exhibits vibration of 20 mils peak-to-peak displacement caused by rotor unbalance. In terms of vibration velocity, 20 mils at 60 CPM (1 Hz) is only 0.0628 in/sec [V = 2(3.14)(1)(0.02/2) = 0.0628]. This level would be considered good for general machinery and little cause for immediate concern. However, keep in mind that the bearing of this machine is being deflected 20 mils. Under these conditions, fatigue may occur due to stress (resulting from the displacement) rather than due to fatigue (caused by the velocity of displacement).

Generally, the most useful presentation of vibration data is a graph showing vibration velocity (expressed in inches/second) on the vertical axis and frequency on the horizontal axis. By analyzing this data, a trained vibration technician can ascertain what kinds of problems exist. A trained technician can learn to read vibration signatures and to interpret what the different peaks in the different frequency ranges indicate. For example, when analyzing a 3600 RPM pump motor, a peak at 3600 RPM indicates some kind of mass imbalance. A peak at 7200 RPM (two times the rotational frequency) generally indicates a bent shaft.

All rotating machinery will exhibit a certain degree of vibration. The question then becomes “How much is too much?” There are no realistic figures for selecting a vibration limit, which, if exceeded, will result in immediate machinery failure. The events surrounding the development of a mechanical failure are too complex to set reliable limits. However, there are some general guidelines that have been developed over the years that can serve as general indication of the condition of a piece of machinery. Some of the vibration equipment manufacturing and supplier companies can provide these guidelines and lessons learned.

Figure 8.10 lists the forcing frequencies associated with machines as guideline for possible source of fault.

Source - Fault Induced by	Frequency (multiple of RPM)
Antifriction bearings	bearing frequecies
Asymmetric shaft	2 X (frequency)
Bent shaft	1 X
Blades & vanes (m)	m X
Casing and foundation distortion	1 X
Couplings (m jaws)	m X
Gears (n teeths)	n X
impact mechanism	multi frequencies - waveform dependent
Mass unbalance	1 X (frequency)
Misallignment	1 X, 2X
Mechanical looseness	odd orders of X (2X, 4X...)

Figure 8.10 Forcing Frequencies Associated with Machines

Most vibration-based PdM programs rely on one or more of the following techniques:

- **Broadband trending** provides a broadband or overall value that represents the total vibration of the machine at the specific measurement point where the data was acquired. It does not provide information on the individual frequency components or machine dynamics that created the measured value. Collected data is compared either to a baseline reading taken when the machine was new (or sometimes data from a new, duplicate machine) or to vibration severity charts to determine the relative condition of the machine.
- **Narrowband trending** monitors the total energy for a specific bandwidth of vibration frequencies and is thus more specific. Narrowband analysis utilizes frequencies that represent specific machine components or failure modes. A narrowband vibration analysis can provide several weeks or months of warning of impending failure. In establishing a vibration monitoring program, one must first determine how often to take sampling data. Different vibration frequencies predict different potential failures.
- **Signature analysis** provides visual representation of each frequency component generated by a machine. With appropriate training and experience, plant personnel can use vibration signatures to determine the specific maintenance required on the machine being studied.

When setting up a vibration monitoring program that uses hand-held vibration instrumentation, it is necessary to ensure that the measurements are taken consistently. A slight variation in the location where a measurement is taken on machinery can significantly alter its accuracy. This becomes an issue especially when several technicians take measurements at different times on the same machinery.

If applied by a trained professional, vibration monitoring can yield information regarding: wear, imbalance, misalignment, mechanical looseness, bearing damage, belt flaws, sheave and pulley flaws, gear damage, flow turbulence, cavitations, structural resonance, and material fatigue.

Detection Interval/Amount of Data Collected The frequency of data collection depends on machine type and failure category. Typically, spot readings of facility assets with hand-held vibration monitoring equipment once per month or once per quarter or 500 operating hours usually provides sufficient warning of impending problems. Facility rotating equipment, e.g., fans and pumps, does not deteriorate fast enough to warrant continual real time data collection. However, critical and expensive assets may warrant having real-time, continuous data collection system.

Spectrum Analysis and Waveform Analysis Spectrum analysis is the most commonly-employed analysis method for machinery diagnostics. In this type of analysis, the vibration technician focuses on analyzing specific "slices" of the vibration data taken over a certain range of CPM. Spectrum analysis can used to identify the majority of all rotating equipment failures (due to mechanical degradation) before failure. Waveform analysis, or time domain analysis, is another extremely valuable analytical tool. Although not used as regularly as spectrum analysis, the waveform often helps the analyst more correctly diagnose the problem.

Torsional Vibration Torsional vibration is often used to detect the vibration associated with the measurement of gear vibration and torque. It is a very useful tool where, due to transmission path attenuation, the casing vibration signal has a signal-to-noise ratio insufficient to detect the problem (i.e., the noise obscures the signal). Torsional vibration is especially effective in situations where unsteady forces excite the resonance of the structure or housing.

Shock Pulse Analysis This type of analysis is used to detect impacts caused by contact between the surfaces of the ball or roller and the raceway during rotation of anti-friction bearings. The magnitude of these pulses depends on the surface condition and the angular velocity of the bearing (RPM and diameter). Spike energy is similar in theory to shock pulse.

Alignment Misalignment of shafted equipment will not only cause equipment malfunctions or breakdowns; it may also be an indicator of other problems. Checking and adjusting alignments used to be a very slow procedure. But the advent of laser alignment systems has reduced labor time by more than half and increased accuracy significantly.

Laser shaft alignment is a natural compliment to vibration analysis. Properly aligning shafts eliminates one of the major causes of vibration in rotating machines and also drastically extends bearing life. For the minimal amount of work involved, the payback is great.

Vibration Equipment For permanent data collection, vibration analysis systems include microprocessor-based data collectors, vibration transducers, equipment-mounted sound discs, and a host personal computer with software for analyzing trends, establishing alert and alarm points, and assisting in diagnostics. Portable hand-held data collectors consist of a hand-held data collection device about the size of a palm-top computer and a magnetized sensing device. Vibration analysis system may cost $10,000 to $120,000, which includes monitoring equipment, software, and primary training.

The effectiveness of vibration monitoring depends on sensor mounting, resolution, machine complexity, data collection techniques, and the ability of the analyst. This last factor, the ability of the analyst, is probably the most important aspect of establishing an effective vibration monitoring program. The analyst must be someone who possesses a thorough understanding of vibration theory and the extensive field experience necessary to make the correct diagnosis of the acquired vibration data.

Infrared Thermography

As one of the most versatile condition-based maintenance technologies available, infrared thermography is used to study everything from individual components of assets to plant systems, roofs, and even entire buildings.

Infrared Thermography (IRT) uses special instruments – cameras to detect, identify, and measure the heat energy objects radiate in proportion to their temperature and emissivity. Midwave-range instruments detect infrared in the 2–5 micron range; longwave-range instruments detect the 8–14 micron range.

Infrared inspections can be qualitative or quantitative. Qualitative inspection concerns relative differences, hot and cold spots, and deviations from normal or expected temperatures. Quantitative inspection concerns accurate measurement of the temperature of the target.

Infrared instruments include an optical system to collect radiant energy from the object and focus it, a detector to convert the focused energy pattern to an electrical signal, and an electronic system to amplify the detector output signal and process it into a form that can be displayed. Most instruments include the ability to produce an image that can be displayed and recorded. These thermographs, as the images are called, can be interpreted directly by the eye or analyzed by computer to produce additional detailed information. High-end systems can isolate readings for separate points, calculate average readings for a defined area, produce temperature traces along a line, and make isothermal images showing thermal contours.

It is essential that infrared studies be conducted by technicians who are trained in the operation of the equipment and interpretation of the imagery. Variables that can destroy the accuracy and repeatability of thermal data, for example, must be compensated for each time data is acquired. In addition, interpretation of infrared data requires extensive training and experience.

Infrared Thermography (IRT) cameras are noncontact, line-of-sight, thermal measurement and imaging systems. Because IRT is a non-contact technique, it is especially attractive for identifying hot and cold spots in energized electrical equipment, large surface areas such as boilers and building roofs, and other areas where "stand off" temperature measurement is necessary. Instruments that perform this function detect electromagnetic energy in the short wave (3–5 microns) and long wave (8–15 microns) bands of the electromagnetic spectrum.

The short wave instrument is the best choice for facilities inspections due to the varied inspections (electrical, mechanical, and structural) encountered. However, the short wave instrument is more sensitive than long wave to solar reflections. Sunlight reflected from shiny surfaces may make those surfaces appear to be "hotter" than the adjacent surfaces when they really are not. IRT instruments–cameras are portable, usually sensitive to within 0.20°C over a range of temperatures from -100 to +3000°C, and accurate within +/-3 percent. In addition, the instrument can store images for later analysis.

IRT inspections attempt the accurate measurement of the temperature of the item of interest. To perform an inspection requires knowledge and understanding of the relationship of temperature and radiant power, reflection, emittance, and environmental factors, as well as the limitations of the detection instrument. This knowledge must be applied in a methodical manner to control the imaging system properly and to obtain accurate temperature measurements.

The qualitative inspections are significantly less time-consuming because the thermographer is not concerned with highly-accurate temperature measurement. In qualitative inspections the thermographer obtains accurate temperature differences (ΛT) between like components. For example, a typical motor control center will supply three-phase power, through a circuit breaker and controller, to a motor. Ideally, current flow through the three-phase circuit should be uniform so the components within the circuit should have similar temperatures. Any uneven heating, perhaps due to dirty or loose connections, would quickly be identified with the IRT imaging system.

IRT can be used very effectively to identify degrading conditions in facilities' electrical systems such as transformers, motor control centers, switchgear, substations, switchyards, or power lines. In mechanical systems, IRT can identify blocked flow conditions in heat exchanges, condensers, transformer cooling radiators, and pipes. IRT can also be used to verify fluid level in large containers such as fuel storage tanks. IRT can identify insulation system degradation in building walls and roofs, as well as refractory in boilers and furnaces. Temperature monitoring, infrared thermography in particular, is a reliable technique for finding the moisture-induced temperature effects that characterize roof leaks, and for determining the thermal efficiency of heat exchangers, boilers, building envelopes, etc.

Deep-probe temperature analysis can detect buried pipe energy loss and leakage by examining the temperature of the surrounding soil. This technique can be used to quantify ground energy losses of pipes. IRT can also be used as a damage control tool to locate mishaps such as fires and leaks.

Thermography is limited to line of sight. Errors can be introduced due to color of material, material geometry, and by environmental factors such as solar heating and wind effects. IRT equipment ranges from simple contact devices such as thermometers and crayons to full-color imaging, computer-based systems that can store, recall, and print the thermal images. The "deep-probe" temperature technique requires temperature probes, analysis software, and equipment to determine the location of piping systems.

Because IRT images are complex and difficult to measure and analyze, training is required to obtain and interpret accurate and repeatable thermal data and to interpret the data. With adequate training and certification, electrical/mechanical technicians and engineers can perform this technique.

Training is available through infrared imaging system manufacturers and vendors. Also, the American Society of Non-destructive Testing (ASNT) has established guidelines for nondestructive testing (NDT) thermographer certification. These guidelines, intended for use in nondestructive testing, may be used as guidelines for thermography in CBM if appropriately applied.

Ultrasonic Testing

Ultrasonic testing is extremely useful in the location and diagnosis of mechanical and electrical problems. Testing instruments are usually portable hand held devices. Their electronic circuitry converts a narrow band of ultrasound (between 20 and 100 kHz) into the audible range so that a user can recognize the qualitative sounds of operating equipment through headphones. Intensity of signal strength is also displayed on the instrument. Ultrasonic instruments–scanners are most often used to detect gas pressure or vacuum leaks.

Ultrasonic detectors are somewhat limited in their use. For example, they may help identify the presence of suspicious vibrations within a machine, but they are not sufficient for isolating the sources or causes of those vibrations.

On the plus side, ultrasonic monitoring is easy, requires minimal training, and the instruments are inexpensive. Airborne ultrasonic devices are highly sensitive listening "guns" (similar in size to the radar speed guns used by police at speed traps). They provide a convenient, nonintrusive means of assessing asset condition. Airborne ultrasonic monitoring is especially easy and useful in testing remote electrical equipment, as well as shielded electrical equipment, e.g., connections inside switchgear and panels. In the case of high voltage insulator failures, airborne ultrasonic devices can often detect faults earlier than infrared thermography can. Except for severe cases where a current path to ground was established, infrared thermography would not detect high-voltage insulation failures because the corona or tracking typically produces little or no heat. Airborne ultrasonic devices can also detect the noise caused by loose connections as they vibrate inside of panels.

Airborne ultrasonic devices operate in the frequency range from 20 to 100kHz and translate the high frequency signal to a signal within the audible human range. This allows the operator to hear changes in noise levels associated with leaks, corona discharges, and other high frequency events. For example, a maintenance technician could use ultrasonic equipment to "hear" a bearing ring and surrounding housing resonating at the resonant frequency. Once detected, a maintenance technician could then proceed to find the cause of the problem such as insufficient lubrication or minor bearing material defects would be the likely cause of this malfunction.

Some of the most common applications of ultrasound detection are:

- Leak detection in pressure and vacuum systems (i.e., boiler, heat exchanger, condensers, chillers, vacuum furnaces, specialty gas systems)
- Bearing inspection
- Steam trap inspection
- Pump cavitations
- Detection of corona in switch gear
- Valve analysis
- Integrity of seals and gaskets in tanks and pipe systems

All operating equipment and most leakage problems produce a broad range of sound. The high frequency ultrasonic components of these sounds are extremely short wave in nature, and a short wave signal tends to be fairly directional. It is therefore easy to isolate these signals from background noises and detect their exact location. In addition, as subtle changes begin to occur in mechanical equipment, the nature of ultrasound allows these potential warning signals to be detected early — before actual failure.

Leak Detection in Mechanical Systems Ultrasound is a very versatile technique that detects the sound of a leak. When a fluid (liquid or gas) leaks, it moves from the high pressure side through the leak site to the low pressure side, where it expands rapidly and produces a turbulent flow. This turbulence has strong ultrasonic components. The intensity of the ultrasonic signal falls off rapidly from the source, allowing the exact spot of a leak to be located.

Generalized gas leak detection is also very easy. An area should be scanned while listening for a distinct rushing sound. With continued sensitivity adjustments, the leak area is scanned until the loudest point is heard.

Some instruments include a rubber focusing probe that narrows the area of reception so that a small emission can be pinpointed. The rubber focusing probe is also an excellent tool for confirming the location of a leak. This is done by pressing it against the surface of the suspected area to determine if the sound of the leak remains consistent. If it decreases in volume, the leak is elsewhere.

Vacuum leaks may be located in the same manner; the only difference being that the turbulence will occur within the vacuum chamber. For this reason, the intensity of the sound will be less than that of a pressurized leak. Though it is most effective with low-mid to gross leaks, the ease of ultrasound detection makes it useful for most vacuum leak problems.

Liquid leaks are usually determined through valves and steam traps, although some successes have been reported in locating water leaks from pressurized pipes buried underground. A product can be checked for leakage if it produces some turbulence as it leaks.

Valves are usually checked for leakage with the contact probe on the downstream side. This is accomplished by first touching the upstream side and adjusting the sensitivity to read about 50% of scale. The downstream side is then touched and the sound intensity is compared. If the signal is lower than upstream, the valve is considered closed; if it is louder than upstream and is accompanied by a typical rushing sound, it is considered to be leaking.

Steam traps are also inspected easily with ultrasonic translators. During the steam trap operation and while observing the meter, trap conditions can be interpreted. The speed and simplicity of this type of test allow every trap in a plant to be routinely inspected.

Leaking tubes in heat exchangers and condensers as well as boiler casing leaks are detectable with ultrasonic translators. In most power plants, the problem of condenser in-leakage is a major concern. Condenser fittings are often routinely inspected using the leak detection method previously described. If a leak is suspected in a condenser tube bundle, it is possible to locate the leak by putting a condenser at partial load and opening up a water box of a suspected tube bundle. After the tube sheet is cleared of debris, the tube sheet is scanned.

Bearing Inspections Ultrasonic inspection and monitoring of bearings is a reliable method for detecting incipient bearing failure. The ultrasonic warning appears prior to a rise in temperature or an increase in driving torque. Ultrasonic inspection of bearing is useful in recognizing the beginning of fatigue failure, brinnelling of bearing surfaces, flooding of (or lack) of lubricant. In ball bearings, as the metal in the raceway, roller, or bearing balls begins to fatigue, a subtle deformation begins to occur. This deforming of the metal will produce an increase in the emission of ultrasonic sound waves.

It is observed that as the lubricant film reduces, the sound level will increase. A rise of about 8 dB over baseline accompanied by a uniform rushing sound will indicate lack of lubrication. When lubricating, add just enough to return the reading to baseline. Some lubricants will need time to run in order to cover the bearing surfaces uniformly.

One of the most frequent causes for bearing failure is over-lubrication. The excess stress of lubricant often breaks bearing seals or causes a buildup of heat, which can create stress and deformity. To avoid over-lubrication, do not lubricate if the baseline reading and baseline sound quality is maintained. When lubricating, use just enough lubricant to bring the ultrasonic reading to baseline. Recently new grease-guns have become available in the market with built-in ultrasonic systems that can provide with right amount of grease. These are very practical and easy to use devices.

Detection in Electrical Systems

Three types of high voltage electrical problems detectable with ultrasound are:

- **Arcing.** An arc occurs when electricity flows through space. Lightning is a good example.
- **Corona.** When voltage on an electrical conductor, such as an antenna or high voltage transmission line, exceeds threshold value, the air around it begins to ionize to form a blue or purple glow.
- **Tracking.** Often referred to as "baby arcing," electricity follows the path of damaged insulation, using surrounding dirt, debris, and moisture as the conductive medium.

Theoretically, ultrasonic detection can be used in low, medium, and high voltage systems; however, applications normally use medium and high voltage systems. When electricity escapes in high voltage lines or when it jumps across a gap in an electrical connection, it disturbs the air molecules around it and generates ultrasound. Often this sound will be perceived as a crackling or frying sound. In other situations, it will be heard as a buzzing sound. In substations and distribution systems, components such as insulators, transformers, insulators, cable, switchgear, bus bars, relays, contractors, junction boxes, and bushings may be tested.

Ultrasonic testing is often used for evaluation at voltages exceeding 2,000 volts, especially in enclosed switchgear. This is especially useful in identifying corona problems. In enclosed switchgear, the frequency of detection of corona greatly exceeds the frequency of serious faults identified by infrared. It is recommended that both tests be used with enclosed switchgear. When testing electric equipment, be sure to follow safety procedures.

The method for detecting electric arc and corona leakage is similar to that discussed in mechanical leak detection. Instead of listening for a rushing sound, a user will listen for a crackling or buzzing sound. Determining whether a problem exists is relatively simple. By comparing sound quality and sound levels among similar equipment, the problem will become easy to identify, even though the sound itself will differ somewhat as it resonates through various types and sizes of equipment.

On lower voltage systems, a quick scan of bus bars will often pick up a loose connection. Checking junction boxes can reveal arcing. As with leak detection, the closer one gets to the leak site, the louder the signal. If power lines are to be inspected and the signal does not appear to be intense enough to be detectable from the ground, a parabolic reflector which is an ultrasonic waveform concentrator, will increase the detection distance of the system and provide pinpoint detection.

Lubricant (Oil) and Wear Particle Analysis

The objective of oil analysis is to determine:

- An asset's mechanical wear condition
- Lubricant condition
- If the lubricant has become contaminated

A wide variety of tests can provide information regarding one or more of these areas. The three areas are not unrelated; changes in lubricant condition and contamination, if not corrected, will lead to machine wear.

Lubricant Condition Bad lubricating oil is either discarded or reconditioned through filtering or by replacing additives. Analyzing the oil to determine the lubricant condition is, therefore, driven by costs. Small machines with small oil reservoirs have the oil changed on an operating time basis. An automobile is the most common example of time-based lubricating oil maintenance. In this example, the costs to replace the automobile oil — which includes the replacement oil, labor to change the oil, and disposal costs — are lower than the cost to analyze the oil, e.g., the cost of sample materials, labor to collect the sample, and the analysis. In the case of automobile oil, time-based replacement is cheaper than analysis due to competition and the economies of scale that have been created to meet the consumer need for replacing automobile oil.

In an industrial set-up, lubricating oil can become contaminated due to the machine's operating environment, improper filling procedures, or through the mixing of different lubricants in the same machine. If a machine is "topped off" with oil frequently, we should send the oil out for analysis periodically to check the machine for any serious problems.

The full benefit of oil analysis can be achieved only by taking frequent samples and trending the data for each asset in the program. The length of the sampling intervals varies with different types of equipment and operating conditions. Based on the results of the analyses, lubricants can be changed or upgraded to meet the specific operating requirements.

It cannot be overemphasized that sampling technique is critical to meaningful oil analysis. Sampling locations must be carefully selected to provide a representative sample and sampling conditions should be uniform so that accurate comparisons can be made.

Standard Analytical Test Types Lubricating oil and hydraulic fluid analysis should proceed from simple, subjective techniques such as visual and odor examination through more sophisticated techniques. The more sophisticated test should be performed when conditions indicate the need for additional information and based on asset criticality.

Visual and Odor Simple inspections can be performed weekly by the equipment operator to look at and smell the lubricating oil. A visual inspection looks for changes in color, haziness or cloudiness, and particles. This test is very subjective, but can be an indicator of recent water or dirt contamination and advancing oxidation. A small sample of fresh lubricating oil in a sealed, clear bottle, can be kept on hand for visual comparison. A burned smell may indicate oxidation of the oil. Other odors could indicate contamination. Odor is more subjective than the visual inspection because people's sensitivity to smell varies, and there is no effective way to compare the odor between samples. The operator must be careful not to introduce dirt into the system when taking a sample.

Viscosity Viscosity is one of the most important properties of lubricating oil; it is often referred to as the structural strength of liquid. The analysis consists of comparing a sample of oil from an asset to a sample of unused oil to determine if thinning or thickening of the oil has occurred during use. Viscosity is critical to oil film control and is key indicator to condition related to the oil and the machine.

Viscosity is a measure of oil's resistance to flow at a specified temperature. A change (increase or decrease) in viscosity over time indicates changes in the lubricant condition, or it may indicate lubricant contamination. Viscosity can be tested using portable equipment, or it can be tested more accurately in a laboratory using the ASTM D445 standard. Viscosity is measured in centistoke (cSt) at $40^{o}C$, and minimum and maximum values are identified by the ISO grade.

Water (Moisture)Test Water (moisture) is generally referred to as a chemical contaminant when suspended in oils. Its effects in bearings, gearing, and hydraulic components can be very destructive. Like particles, control must be established to minimize water accumulation to the oil and machines.

Water in lubricating oil and hydraulic fluid contributes to corrosion and formation of acids. Small amounts of water (less than 0.1 percent) can be dissolved in oil and can be detected using the crackle test or infrared spectroscopy (minimum detectable is approximately 500 ppm), the ASTM D95 distillation method (minimum 100 ppm). If greater than 0.1 percent water is suspended or emulsified in the oil, the oil will appear cloudy or hazy. Free water in oil collects in the bottom of oil reservoirs and can be found by draining them from the bottom.

Using a titration process with a Karl Fischer method, low levels of water can be detected and quantified. The volumetric titration test uses ASTM D1744, and Coulometric titration uses ASTM D4928. This test is useful when accepting new oil.

Wear Particle Count High particle counts indicate that machinery may be wearing abnormally or that failures could be caused by blocked orifices. Particle count tests are especially important in hydraulic systems.

The wear particle test emphasizes the detection and analysis of current machine anomalies — the symptoms of failure. The oil serves as the messenger of information on the health of the machine. When a machine component is experiencing some level of failure such as rubbing, it will shed particles in the oil. The presence of abnormal level of wear particles, their size, shape, color, orientation, and elements define the cause, source, and severity of the condition.

Total Acid Number (TAN) Total acid number (TAN) is a measure of the amount of acid or acid-like materials in oil. It is an indicator of the lubricating oil condition and is monitored relative to the TAN of new oil. In some systems, the TAN will also be used to indicate acid contamination. TAN is measured in milligrams of potassium hydroxide (KOH) per gram of oil (mg KOH/g). KOH is used in a titration process and the end point is indicated by color change (ASTM D974) or electrical conductivity change (ASTM D664).

Total Base Number (TBN) Total base number (TBN) indicates oil's ability to neutralize acidity. Low TBN is often an indicator that the wrong oil is being used for the application, intervals between oil changes are too long, oil has been overheated, or a high-sulfur fuel is being used.

Spectrometric Metals Analysis Also known as emission spectroscopy, this test examines the light (spectrum) emitted from the sample during testing, and identifies about 21 metals. Metals are categorized as wear, contaminate, or additive metals. The procedure identifies both soluble metal and metal particles.

Infrared Spectroscopy This test is also known as infrared analysis, infrared absorption spectroscopy or spectrophotometry, and Fourier Transform Infrared (FTIR) spectroscopy. The technique examines the infrared wavelength that is absorbed by the oil sample. The test is used to identify nonmetallic contamination and lubricant conditions (e.g., oxidation, anti-oxidant, other additive depletion). Connecting computer expert system with known oil spectrums can produce highly accurate diagnosis of small changes in the oil condition.

Analytical Ferrography Analytical ferrography is often initiated based on changes in Direct Reading (DR) ferrograph indicating increases in metal or particle counts. DR Ferrograph quantitatively measures the concentration of ferrous wear particles in lubricating or hydraulic oil.

The analytical ferrography is qualitative and requires visual examination and identification of wear particles. Properties and features of the wear debris are inventoried and categorized. This includes size, shape, texture, color, light effect, density, surface oxide, etc.

This analysis is sometimes performed on a regular basis on expensive or critical machines. The test process is labor intensive and involves the preparation of sample and examination under magnification. Results vary with the analyst's capability, but the procedure can provide detailed information regarding wear: e.g., wear type (rubbing, sliding, cutting), color, particle types (oxide, corrosive, crystalline), and other nonferrous particles. This detailed information can be critical in finding the root cause of wear problems.

Foaming Some oil may have anti-foam agents added to improve the lubrication capability in specific applications such as gear boxes or mixers. ASTM test D892 can be used to test the oils foam characteristics. The test blows air through a sample of the oil and measures the foam volume.

Rust Prevention Some systems are susceptible to water contamination due to equipment location or the system operating environment. In those cases, the lubricating oil or hydraulic fluid may be fortified with an inhibitor to prevent rust. The effectiveness of rust prevention can be tested using ASTM D665 (or ASTM D3603).

Rotating Bomb Oxidation Test (RBOT) Also known as the Rotary Bomb Oxidation Test, ASTM D 2272 is used to estimate oxidation stability and the remaining useful life of oil. The test simulates aging, identifying when rapid oxidation takes place, and indicating that anti-oxidants have been depleted. The test is not a one-time test; it must be performed over time, starting with a baseline test of the new oil. Subsequent tests are necessary to develop the trend line. Because of the high cost and the multiple tests required, this test is usually only performed on large volume reservoirs or expensive oil.

Sampling and Frequency Oil samples must be collected safely and in a manner that will not introduce dirt and other contaminates into the machine or system, or into the sample. It may be necessary to install permanent sample valves in some lubricating systems. The oil sample should be representative of the oil being circulated in the machine. The sample should, therefore, be collected from a mid-point in reservoirs and upstream of the filter in circulating systems. Clean sample collection bottles and tubing must be used to college the sample. Oil sample pumps for extracting oil from reservoirs are used to avoid contamination. Samples must be collected from the same point in the system to ensure consistency in the test analysis; therefore, the maintenance procedure must provide detailed direction on where and how to collect samples. It is good practice to have operators collect the samples.

Typically, lubricating oil analysis should be performed on a quarterly or yearly or 500 / 2000 hours of operations basis for most of the assets. The analysis schedule should be adjusted based on asset usage, criticality, or cost. Analyze more frequently for machines that are indicating emerging problems; less frequently for machines that operate under the same conditions and are not run on a continuous basis. A new baseline analysis will be needed following machine repair or oil change out.

Grease is usually not analyzed on a regular basis. Although most of the testing that is done on oil can also be done on grease, getting a representative sample is usually difficult. To get a good sample that is a homogeneous mixture of the grease, contaminants, and wear, the machine may have to be disassembled.

Oil Contamination Program A concern common to all machines with lubricating oil systems is keeping dirt and moisture out of the system. Common components of dirt, such as silica, are abrasive and naturally promote wear of contact surfaces. In hydraulic systems, particles can block and abrade the close tolerances of moving parts. Water in oil promotes oxidation and reacts with additives to degrade the performance of the lubrication system. Ideally, there would be no dirt or moisture in the lubricant; this, of course, is not possible. The lubricant analysis program must therefore monitor and control contaminants.

Large systems with filters will have steady-state levels of contaminates. Increases in contaminates indicate breakdown in the system's integrity (leaks in seals, doors, heat exchangers, etc.) or degradation of the filter. Unfiltered systems can exhibit steady increases during operation. Operators can perform a weekly visual and odor check of lubricating systems and provide a first alert of contamination. Some bearing lubricating systems may have such a small amount of oil that a weekly check may not be cost effective.

A basic oil contamination control program can be implemented in three steps:

1. Establish the target fluid cleanliness levels for each machine fluid system.
2. Select and install filtration equipment (or upgrade current filter rating) and contaminant exclusion techniques to achieve target cleanliness levels.

3. Monitor fluid cleanliness at regular intervals to achieve target cleanliness levels.

Electrical Condition Monitoring

Electrical condition monitoring encompasses several technologies and techniques used to provide a comprehensive system evaluation. Electrical equipment represents a major portion of a facility's capital investment. From the power distribution system to electric motors, efficient operation of the electrical systems is crucial to maintaining operational capability of a facility.

Monitoring key electrical parameters provides the information to detect and correct electrical faults such as high resistance connections, phase imbalance, and insulation breakdown. Because faults in electrical systems are seldom visible, these faults are costly due to increased electrical usage and increased safety concerns; they involve life cycle cost issues due to premature replacement of expensive assets. According to the Electric Power Research Institute (EPRI), voltage imbalances of as little as 5% in motor power circuits result in a 50% reduction in motor life expectancy and efficiency in a three-phase AC motors. A 2.5% increase in motor temperatures can be generated by the same 5% voltage imbalance accelerating insulation degradation.

Monitoring intervals of several weeks to several months for various technologies will provide sufficient condition information to warn of degrading equipment condition. Specific expectations of the length of warning provided should be factored into developing monitoring intervals for specific technologies.

Several of the technologies outlined below are also effective when used for acceptance testing and certification for new systems.

Motor Current Readings Clamp-on ammeter attachments provide the capability of taking actual current draw information while the equipment is operating. On three-phase equipment, comparison of current draws can reveal phase imbalance conditions.

Motor Analysis Until fairly recently, predictive maintenance technologies for motors were limited to vibration testing, high-voltage surge testing for winding faults, meg-Ohm and high-potential tests for insulation resistance to ground, and voltage and current tests for testing phase balance. Many of these tests still have their place in plant maintenance, but several of them are dangerous or harmful when tests are conducted with motors in place.

New technologies allow for portable, safe, and trendable tests that can be used for more accurate troubleshooting or identifying problem areas. Each of these technologies has its strengths and weaknesses. But as part of a CBM program, they can accurately detect potential faults and avoid costly downtime.

Static Motor Circuit Analysis (MCA) MCA provides a low-voltage, safe method of testing motor winding and rotor defects. The best instruments for this analysis use impedance-based tests coupled with insulation-to-ground testing. Impedance-based instruments are simple to use, and the results are easy to evaluate. Inductive-based instruments are for trending. Tests detect faults in motors, cabling, and connections. Motors must be de-energized.

Motor Current Signature Analysis (MCSA) MCSA is performed by taking current data and analyzing it using Fourier transform analysis. The primary purpose of the test is rotor bar fault detection, but it is also useful for detecting rotor faults and power quality problems as well as other motor and load defects in later stages of failure. Motors must be energized and loaded during tests.

MCSA is a method of detecting the presence of broken or cracked rotor bars or high resistance connections in end rings. Motor current spectrums in both time and frequency domains are collected with a clamp-on ammeter and Fast Fourier Transform (FFT) analyzer. Rotor bar problems will appear as side-bands around the power supply line frequency. MCSA evaluates the amplitude of the side bands that occur about the line frequency.

High Potential Testing (HiPot) HiPot testing applies a voltage equal to twice the operating voltage plus 1000 volts to cables and motor windings to test the insulation system. This is typically a "go/no-go" test. Industry practice calls for HiPot tests on new and rewound motors. This test stresses the insulation systems and can induce premature failures in marginal motors. Due to this possibility, HiPot is not recommended as a routinely repeated condition monitoring technique, but as an acceptance test. An alternative use of the equipment is to start with lower voltage and increase the applied voltage in steps and measure the change in insulation resistance readings.

Surge Comparison Testing This testing uses high-voltage pulses to detect winding faults. Only experienced operators should conduct these tests because of the potentially harmful effects of high voltage impressed on used windings and cables. There are also challenges with testing assembled motors due to rotor effects on the motor circuit. The motor being tested must be de-energized with controls disconnected.

Surge Testing uses equipment based on two capacitors and an oscilloscope to determine the condition of motor windings. This is a comparative test evaluating the difference in readings of identical voltage pulses applied to two windings simultaneously. Like HiPot testing, the applied voltage equals two times operating voltage plus 1000 volts. This test is primarily an acceptance, go/no-go test. Data are provided as a comparison of waveforms between two phases indicating the relative condition of the two phases with regard to short circuits. The readings for a particular motor can be trended, but the repeated stress of the insulation system is not recommended.

Conductor Complex Impedance The total resistance of a conductor is the sum of its resistance, capacitive impedance, and inductive impedance. Accurate measurement of the conductor impedance allows minor degradations in a motor to be detected and addressed prior to motor failure. The condition of the insulation system can be determined by measuring the capacitance between each phase and ground. The presence of moisture or other conducting substance will form a capacitor with the conductor being one plate, the insulation the dielectric, and the contaminate forming the second plate. Maintaining proper phase balance is imperative to efficient operation and toward realizing the full lifetime of electrical equipment.

Megohmmeter Testing A hand-held generator (battery powered or hand cranked) is used to measure the insulation resistance phase-to-phase or phase-to-ground of an electric circuit. Readings must be temperature-corrected to trend the information. Winding temperatures affect test results. An enhanced technique compares the ratio of the Megohmmeter readings after 1 minute, and then again compare the readings after 10 minutes. This ratio is referred to as the polarization index.

Time Domain Reflectometry In this test, a voltage spike is sent through a conductor. Each discontinuity in the conductor path generates a reflected pulse. The reflected pulse and time difference between initial pulse and reception of the reflected pulse indicate the location of the discontinuity.

Radio Frequency (RF) Monitoring RF monitoring is used to detect arcs caused by broken windings in generators. It consists of establishing RF background levels and the amplitude trend over a narrow frequency band.

Power Factor and Harmonic Distortion Maintaining optimum power factor maximizes the efficient use of electrical power. The power factor is the ratio of real power to reactive power usage. Dual channel data-loggers are used to determine the phase relationship between voltage and current, then to calculate the power factor. If this process detects a low power factor, subsequent engineering analysis will be required to devise a means of improving power system power factor.

Application of Various Technologies to Electrical Assets Specific electrical assets that can be monitored by CBM technologies are:

- **Electrical Distribution Cabling.** Megohmmeter, Time Domain Reflectometry, HiPot, Infrared Thermography, and Airbourne Ultrasonics.
- **Electrical Distribution Switchgear and Controllers.** Timing, Visual Inspection, IRT, and Airborne Ultrasonics
- **Electrical Distribution Transformer.** Oil Analysis, Turns Ratio, Power Factor, and Harmonic Distortion
- **Electrical Motors.** Current Draw, Motor Current Spectrum Analysis, Motor Circuit Analysis, Megohmmeter. HiPot, Surge Test, Conductor Complex Impedance, Starting Current, and Coast-Down Time
- **Generators.** Megohmmeter, RF, and Coast-Down Time

Technologies Limitations

The technologies discussed earlier can be divided into two categories:

- **Energized.** These technologies can safely provide information on energized systems and require the system be energized and operational. They include IRT, Ultrasonics, Motor Current Readings, Starting Current, Motor Current Spectrum Analysis RF, Power Factor, and Harmonic Distortion.
- **De-Energized.** These technologies require the circuit to be de-energized for safe usage includes Surge Testing, HiPot Testing, Time Domain Reflectometry (TDR), Megohmmeter, Motor Circuit Analysis, Transformer Oil Analysis, Turns Ratio, and Conductor Complex Impedance.

Each technology will require specific initial conditions to be set prior to conducting the test. For instance, prior to an IRT survey, typical equipment powered through the switch board should be running to bring the distribution equipment to normal operating temperatures. Higher load accentuates problem areas. Conducting the survey at low load conditions may allow a problem to remain undetected.

HiPot and surge testing should be performed with caution. The high voltage applied during these tests may induce premature failure of the units being tested. For that reason, these tests normally are performed only for acceptance testing, not for condition monitoring.

Other Miscellaneous Non-Destructive Testing

Non-Destructive Testing (NDT) evaluates material properties and quality of expensive components or assemblies without damaging the product or its function. Typically, NDT has been associated with the welding of large high-stress components such as pressure vessels and structural supports. Process plants such as refineries or chemical plants use NDT techniques to ensure integrity of pressure boundaries for systems processing volatile substances.

The following are various NDT techniques.

Radiography Radiography is performed to detect sub-surface defects. Radiography or X-ray is one of the most powerful NDT techniques available in industry. Depending on the strength of the radiation source, radiography can provide a clear representation (radiograph) of discontinuities or inclusions in material several inches thick. X-ray or gamma ray sensitive film is placed on one surface of the material to be examined. The radiation source is positioned on the opposite side of the piece. The source may be either a natural gamma emitter or a powered X-ray emitter. The source is accurately aligned to ensure the proper exposure angle through the material. When all preparations and safety precautions are complete, the radiation source is energized or unshielded.

Radiography, though a versatile tool, is limited by the potential health risks. Use of radiography usually requires the piece be moved to a special shielded area, or that personnel be evacuated from the vicinity to avoid exposure to the powerful radiation source required to penetrate several inches of dense material.

Ultrasonic Testing (Imaging) Ultrasonic imaging provides detection of deep sub-surface defects. Ultrasonic inspection of welds and base material is often an alternative or complementary NDT technique to radiography. Though more dependent on the skill of the operator, ultrasonic does not produce the harmful radiation entailed with radiography. Ultrasonic inspection is based on the difference in the wave reflecting properties of defects and the surrounding material. An ultrasonic signal is applied through a transducer into the material being inspected. The speed and intensity with which the signal is transmitted or reflected to a transducer provides a graphic representation of defects or discontinuities within the material. A couplant fluid is often used to provide a uniform transmission path among the transducer, receiver, and the material of interest. Transducer configurations differ depending on the type of system used. Some systems use a single transducer to transmit and receive the test signal. Others use a transmit transducer in conjunction with a separate receive transducer. Dual transducer systems may be configured with both transducers on the same surface of the material or with transducers on the opposite surfaces of the material.

Three scan types are most commonly used: "A Scan," "B Scan," and "C Scan." A-Scan systems analyze signal amplitude along with return time or phase shifts the signals travel between a specific surface and discontinuities. B-Scan systems add signal intensity modulation and capability to retain video images. C-Scan systems include depth gating to eliminate unwanted returns.

Due to the time and effort involved in surface preparation and testing, ultrasonic inspections are often conducted on representative samples of materials subjected to high stress levels, high corrosion areas, and large welds.

Magnetic Particle Testing (MPT) The Magnetic Particle Testing uses magnetic particle detection of shallow sub-surface defects. It is a very useful technique for localized inspections of weld areas and specific areas of high stress or fatigue loading. MPT provides the ability to locate shallow sub-surface defects. Two electrodes are placed several inches apart on the surface of the material to be inspected. An electric current is passed between the electrodes producing magnetic lines. While the current is applied, iron ink or powder is sprinkled in the area of interest. The iron aligns with the lines of flux. Any defect in the area of interest will cause distortions in the lines of magnetic flux, which will be visible through the alignment of the powder. Surface preparation is important because the powder is sprinkled directly onto the metal surface and major surface defects will interfere with sub-surface defect indications. Also, good electrode contact and placement is important to ensure consistent strength in the lines of magnetic flux.

A major advantage of MPT is its portability and speed of testing. The hand-held electrodes allow the orientation of the test to be changed in seconds. This allows for inspection of defects in multiple axes of orientation. Multiple sites can be inspected quickly without interrupting work in the vicinity. The equipment is portable and is preferred for on-site or in-place applications. The results of MPT inspections are recordable with high quality photographs.

Hydrostatic Testing Hydrostatic Testing is another NDT method for detecting defects that completely penetrate pressure boundaries. Hydrostatic Testing is typically conducted prior to the delivery or operation of completed systems or subsystems that act as pressure boundaries. During the hydrostatic test, the system to be tested is filled with water or the operating fluid. The system is then sealed and the pressure is increased to approximately 1.5 times operating pressure.

This pressure is held for a defined period. During the test, inspections are conducted to find visible leaks to well as monitor pressure drop and make-up water additions. If the pressure drop is out of specification, any leaks must be located and repaired. The principle of hydrostatic testing can also be used with compressed gases. This type of test is typically called an air drop test and is often used to test the integrity of high pressure air or gas systems.

Eddy Current Testing Eddy current testing is used to detect surface and shallow subsurface defects. Also known as electromagnetic induction testing, eddy current testing provides a portable and consistent method for detecting surface and shallow subsurface defects. This technique provides the capability of inspecting metal components quickly for defects or homogeneity. By applying rapidly varying AC signals through coils near the surface of the test material, eddy currents are induced into conducting materials. Any discontinuity that affects the material's electrical conductivity or magnetic permeability will influence the results of this test. Component geometry must also be taken into account when analyzing results from this test.

A set of magnetizing coils are used to induce electrical currents (eddy currents) into the component being tested. The induced currents produce magnetic fields that are then detected by a set of sensing coils. Typically, the two sets of coils are combined into a single probe. The frequency of the AC signals used (5–10 MHz) determines the depth of penetration through the material for the eddy currents. Lower excitation frequencies increase the penetration depth and improve effectiveness in detecting deeper defects. Higher frequencies are used to enhance detection of surface defects. Analysis equipment senses several parameters including magnitude, time lag, phase angles, and flow patterns of the resulting magnetic fields.

8.4 Summary

Reliability-Centered Maintenance, often known as RCM, is a maintenance improvement approach focused on identifying and establishing the operational, maintenance, and design improvement strategies that will manage the risks of asset failure most effectively. The technical standard SAE JA1011 has established evaluation criteria for RCM, which specifies that RCM address, at a minimum, the following seven questions:

1. What is the asset or component supposed to do? (functions)
2. In what ways can it fail to provide the required functions? (functional failures)
3. What are the events that cause each failure? (failure modes)
4. What happens when each failure occurs? (failure effect)
5. Why does the failure matter? (failure consequences)
6. What task can be performed proactively to prevent, or to diminish to a satisfactory degree, the consequences of the failure?
7. What must be done if a suitable preventive task cannot be found?

Thus, RCM is a process that determines what must be done to ensure that assets continue to do what their users need them for in a certain operating context. RCM analysis provides a structured framework for analyzing the functions and potential failures of assets. RCM is a maintenance / PM plan optimizing strategy.

Condition Based Maintenance (CBM) is a process that determines what must be done to ensure that assets continue to function cost-effectively in the desired manner based on actual operating environment. CBM is based on using real-time data to assess the condition of the assets utilizing predictive maintenance technologies. The data and its analysis help us to make better decision to optimize maintenance resources. CBM will determine the equipment's health, and act only when maintenance is actually necessary.

Condition Based Maintenance endeavors to predict impending failure based on actual operating data instead of relying on traditional Preventive Maintenance, thus generally eliminating unnecessary maintenance performed.

Thus, CBM is another maintenance optimizing strategy. In fact when it used with RCM in establishing maintenance tasks, it produces a much better return on investment.

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Chapter 9

Managing Performance

*"You cannot manage something you cannot control,
and you cannot control something you cannot measure."
— Peter Drucker*

After reading the chapter, reader will be able to understand:

- What to measure and why to measure performance
- Differences between lagging and leading indicators
- Key performance indicators
- A balanced scorecard
- Benchmarks and benchmarking

9.1 Introduction

An organization must measure and analyze its performance if it is to make the improvements needed for staying in business in a competitive market place. The performance measures must be derived and aligned with the organization's goals and strategies of the business. They should be centered on the critical information and data related to the key business processes and outputs, and should be focused on improving results.

Data needed for process improvement and performance measurement includes information about products and services, assets performance, cost of operations, and maintenance. This data is analyzed to determine trends, cause and effects, and the underlying reasons for certain results that may not be evident without an analysis. Data are also used to serve a variety of purposes, such as planning, projections, performance reviews, and operations improvements, and for comparing an organization's performance with the "best practices" benchmarks.

A key component of improvement process involves the creation and use of performance indicators, also known as metrics. These metrics are measurable characteristics of products, services, and processes related to the business. They are used by an organization to track and improve its performance. Metrics should be selected to best represent the factors that lead to improved operations, including maintenance and customer satisfaction. A comprehensive set of measures or metrics tied to the business activities and customers should be based on long- and short-term goals of the organization. Metrics need to be constantly reviewed and aligned with the new or updated goals of the organization and become part of its strategic plan.

Metrics based on the priorities of the strategic plan make lasting improvements to the key business drivers of the organization. Processes are then designed to collect information relevant to these metrics and reduce them to numerical form for easy dissemination and analysis.

The value of metrics is in their ability to provide a factual basis in the following areas:

- Strategic feedback to show the present status of the organization from various perspectives
- Diagnostic feedback into various processes to guide improvements on a continuous basis
- Trends in performance over time as the metrics are tracked
- Feedback around the measurement methods themselves in order to track correct metrics

In most businesses, success is easily measured by looking at the bottom line — the profit. But what's the bottom line for maintenance as a business function? To better understand how to evaluate maintenance business performance, it's helpful to examine how businesses generate profit. In simple terms, businesses generate profit by selling goods and services and by minimizing their costs. Obviously, revenues generated from sales must exceed the costs.

Customers generally demand value. Key components of value are: timeliness, quality, price, and return on investment (ROI). Therefore, metrics for maintenance and reliability should reflect how an organization is providing value to its customers in terms of timely maintenance (availability of assets), quality of service (minimum rework), controlling costs, etc. Thus, maintenance as a business function must develop its internal metrics to evaluate its performance in terms of these parameters.

The Benefits of Performance Measurement

Accountability

Well-designed performance measures document progress toward achievement of goals and objectives, thereby motivating and catalyzing organizations to fulfill their obligations to their employees, stakeholders and customers.

Resources / Budget Justification

Because it ties activities to results, performance measurement becomes a long-term planning tool to justify proper resource or budget allocation.

Ownership and Teamwork

By providing a clear direction for concentrating efforts in a particular functional area, performance measurement provides more employees participation in problem solving, goal setting, and process improvements. It helps set priorities and promotes collaboration among departments and business areas.

Communication — A Common Language

Achievements of goals through metrics can enhance employee understanding and support of management strategies and decisions. They also give employees a common language to communicate, alert them to potential problem areas, and encourage them to share knowledge. Therefore, performance metrics, if properly designed and implemented, enhance productivity and reduce cost.

Key Terms and Definitions

Benchmark

A standard measurement or reference that forms the basis for comparison; this performance level is recognized as the standard of excellence for a specific business process.

Benchmarking

American Productivity and Quality Council (APQC) defines benchmarking as the process of identifying, learning, and adapting outstanding practices and processes from any organization, anywhere in the world, to help an organization improve its performance. Benchmarking gathers the tacit knowledge — the know-how, judgments, and enablers.

Benchmarking Gap

The difference in performance between the benchmark for a particular activity and the level of other organizations. It is the measured performance advantage of the benchmark organization over other organizations.

Best-in-Class

Outstanding process performance within an industry; words used as synonyms are best practice and best-of-breed.

Best practice

There is no single best practice because what is considered the best is not always best for everyone. Every organization is different in some ways in their missions, cultures, environments, and technologies. What is meant by best are those practices that have been shown to produce superior results.

Generic Benchmarking

Process benchmarking that compares a particular business function or process with other organizations, independent of their industries.

Goals

The numerical target value or observed performance that indicates the strategic direction of an organization.

Internal Benchmarking

Benchmarking that is performed within an organization by comparing similar business units or business processes.

Metric

A metric is a standard measure to assess performance in a particular area. Metrics are at the heart of a good, customer-focused process management system and any program directed at continuous improvement. The focus on customers and performance standards show up in the form of metrics that assess an organization's ability to meet customer needs and business objectives.

Networking

A meeting of independent participants who develop a degree of interdependence and share a coherent set of values and interests.

Objective

The set of results to be achieved that will deploy a vision into reality.

Performance

The results of activities of an organization over a given period of time.

Performance Measurement

The use of evidence to determine progress toward specific, defined organizational objectives. This includes both evidence of actual fact, metrics such as measurement of PM backlog or Scheduling compliance, and measurement of customer perception that may be accomplished through a customer satisfaction survey. The performance measurement as defined by the National Performance Review:

"A process of assessing progress toward achieving predetermined goals, including information on the efficiency with which resources are transformed into goods and services (outputs), the quality of those outputs, how well they are delivered to the customer and the extent to which customers are satisfied and outcomes, the results of a program activity compared to its intended purpose, and the effectiveness of operations in terms of their specific contributions to program objectives."

Vision

The achievable dream of what an organization wants to do and where it wants to go.

World-Class

Leading performance in a process independent of industry, function, or location.

9.2 Identifying Performance Measures

It is often said that "what gets measured gets done." Getting things done, through people, is what management is all about. Measuring things that get done and the results of their effort is an essential part of successful management. But too much emphasis on measurements or the wrong kinds of measurements may not be in the best interest of the organization.

A few vital indicators which are important for evaluating process performance are called KPIs — Key Performance Indicators. KPIs are an important management tool; they measure business performance, including maintenance. There are few "hard" measures of maintenance output and the metrics that are commonly used are often easy to manipulate. Maintenance and operations KPIs must be integrated to make them effective and balanced. There are three other criteria that should be considered when deciding what aspects of maintenance to measure:

1. The performance measures should encourage the right behavior.
2. They should be difficult to manipulate to "look good."
3. They should not require a lot of effort to measure.

Some metrics may encourage people to do things that we do not want. A common metric is "adherence to weekly work schedule" for maintenance work. It's easy to achieve a high adherence to schedule by scheduling *less* work, through over-estimating work orders. However, what we really want is higher productivity, which can often be achieved by challenging people and scheduling *more* work, but with better work estimating. Thus the wrong measurement may work against us. Like "adherence to schedule," some other metrics, such as time spent on Preventive Maintenance (PM) work, percent re-work, and percent emergency work are easy to manipulate.

The KPIs which are truly relevant and satisfy the criteria listed above should be considered only for implementation. A good example comes from an organization trying to improve turnaround and shutdown planning, where a new target of completing all planning work two or three weeks in advance of a shutdown has been set and agreed upon. All of its shutdown work orders have a specific code. Therefore, a simple report from the CMMS listing all purchase requisitions against work orders for a specific shutdown that were originated less than two or three weeks in advance will provide a very useful measure to evaluate planning performance. This metric supports the right behavior, is unlikely to be manipulated, and is easy to measure. It will also provide information on where to take action and when to recognize good planning efforts.

Metrics such as the one in this example are of immense value when measuring the success of efforts to implement better practices and to change the behavior. These metrics may in turn be discontinued when the new and improved practices become a habit.

Metrics Development Process

The first step in developing metrics is to involve the people who are responsible for the work to be measured. They are the most knowledgeable about the work. Once these people are identified and involved, it is necessary to:

1. Identify critical work processes and customer requirements.
2. Identify critical results desired and align them to customer requirements.
3. Develop measurements for the critical work processes or critical results.
4. Establish performance goals, standards, or benchmarks.

A ***SMART*** test can be used to ensure the quality of a particular performance metric. Here, the letters in SMART represent:

S = Specific. Be clear and focused to avoid misinterpretation. The metric should include measurement assumptions and definitions and should be easily interpreted.

M = Measurable. The metric can be quantified and compared to other data. It should allow for meaningful statistical analysis. Avoid "yes/no" measures except in limited cases such as start-up or systems-in-place situations.

A = Attainable. The metric is achievable, reasonable, and credible under conditions expected.

R = Realistic. It fits into the organization's constraints and is cost-effective.

T = Timely. It's do-able, data is available within the time needed.

Figure 9.1 lists a few examples of key maintenance and reliability related metrics

Maintenance and Reliability Metrics:

Plant / Organization / Process
Maintenance Costs % of RAV = Total Maintenance Cost $ / Total Asset Replacement Value (RAV)
Maintenance Costs per Unit Output = Maintenance Cost $ / Total number of Unit Produced
Return on Assets (RONA) = Plant or Process Contribution (Plant Revenue – Cost) $ / Total Plant or Process Value (RAV) $
Percentage Overtime = Maintenance Overtime Hours / Total Maintenance Hours
Training Hours (or $) / Person per Year = Total Training Hours (or $) / Total Maintenance Hours (or $)
Number of Papers Presented or Written for M&R Conference & Magazines / Maintenance budget ($ M)
Number of Certified M&R Personnel in % = # of Certified Personnel / Total # of M&R Personnel
Safety Performance = OSHA Recordable Injuries/200K hours

Overall Asset / System / Process
Availability = Uptime / (Uptime + Downtime) or MTBF / (MTBF + MTTR)
Downtime % of Total Scheduled (Operating) Hours = Downtime Hours Due to Failures / Total Scheduled Operating Hours
Overall Equipment Effectiveness (OEE) = % Availability X % Performance X % Quality

Planning & Scheduling and MRO Store
Reported Hours in CMMS % of Paid Hours = Hours Reported in CMMS for a Period / Maintenance Hours Paid for same Period
Work Expended on Blanket Work Orders % of Total = Hours Consumed on Blanket WOs / Total Maintenance Hours Worked
Planned Work as % of Total Work = Planned Work Hours / Total Maintenance Work Hours
Planning Accuracy = Actual Hours It Took for Planned Work / Estimated Hours for Planned Work
Schedule Compliance (by Hours or Tasks) = Scheduled Work Accomplished / Total Scheduled Work
Unscheduled Work in % (Emergency or Schedule Break in Work)
= Unscheduled Work (Emergency or Breakdowns) / Total Work (In man-hours or number of work orders)
Labor Effectiveness (Wrench Time) in % = Hands on Work in Hours by Craft Employees / Total Work in Hours
Rework (Work Quality in %) = Work needing to be Reworked / Total Work in # or Hours
Work Orders Closed with Comments % (Data Quality) = Work Orders or Tasks with No Close Out Good Data/Total WO or Tasks
Inventory Turns (MRO Store) = Inventory issued in a Year ($) / Average Inventory in a Year ($)
Inventory Accuracy in % = Items Found in Right Location and in Right Quantity / Total Number of Items Checked

Maintenance, Preventive & CBM/PdM
Preventive and CBM/PdM Hours % of Total Hours = PM+CBM Hours in a Period / Total Maintenance Hours
Preventive and CBM/PdM Schedule Compliance =Actual PM+CBM Tasks Completed / Total PM+CBM Tasks Scheduled
Work Created by PM & CBM/PdM % of Total Hours = Est. Work Hours Created by PM+CBM / Total PM+CBM Work Hours Completed
Root Cause Failure Analysis (RCFA) Performed for Failures in % = # of RCFA Performed / Total # of Failures

Reliability Program

Figure 9.1 List of Maintenance and Reliability Metrics.

Leading and Lagging Indicators

A simple way to determine if a metric is leading or lagging is to ask the question, "Does the metric allow us to look into the process, or are we outside of the process looking at the results?" Leading indicators are forward looking and help manage the performance of an asset, system, or process, whereas lagging indicators tell how well we have managed.

Process measures are leading indicators. They offer an indication of task performance with a lead time to manage for successful results. For example, a leading maintenance process indicator will measure how proactive the planning or scheduling function has been in preparing preventive and condition-based maintenance work packages or to monitor the percentage of PM / CBM inspections completed per schedule. If people are doing all the right things, then the expectation is that improved results will follow. The leading process indicators are typically more immediate than lagging measures of results. We must manage by the leading indicators. Some examples of M&R-related leading metrics are:

- % Schedule compliance
- % Planned work
- % PM / CBM work compliance (completed on time)
- Work order cycle time
- % Rework
- Planner to craft workers ratio

Lagging indicators are results that occur after the fact. They monitor the output of a process. They measure the results of how well we have managed an asset, process, or overall maintenance business. Some examples of M&R-related lagging metrics are:

- Maintenance cost as % of RAV
- Return on Net Assets (RONA)
- Asset Availability
- MTBF
- OEE
- Maintenance Training Man-hours or $

Figure 9.2 shows a hierarchical model of lagging and leading indicators.

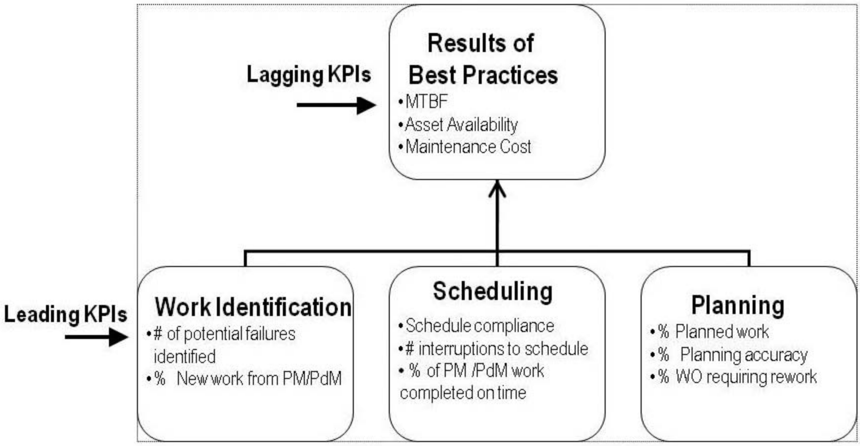

Figure 9.2 Leading and Lagging KPI Model

On a cautionary note, an indicator could be both leading or lagging. For example, PM/CBM work compliance is a lagging indicator — the result of how much PM/CBM work is completed — when viewed in the context of work execution. However, when viewed as an indicator of asset reliability, PM/CBM compliance is a leading indicator of the reliability process. Higher PM/CBM work compliance predicts or very likely leads to improved asset reliability. Similarly, improved asset reliability will lead to reduced maintenance costs, which is a lagging indicator of the maintenance process.

Whether leading or lagging, metrics should be used to provide information on where the process is working well and where it isn't. In doing so, these metrics help build on successes and lead to making process changes where unfavorable trends are developing.

Balanced Scorecard

Most of the time, we measure what's important from the financial and productivity prospective of a process or an organization. The balanced scorecard suggests that we view the process or an organization from four perspectives. We should also develop metrics, collect data, and analyze the data relative to each of these perspectives to balance out any bias.

The Balanced Scorecard is a strategic management approach developed in the early 1990s by Dr. Robert Kaplan of Harvard Business School, and Dr. David Norton. As the authors describe the approach, *"The balanced scorecard retains traditional financial measures. But financial measures tell the story of past events, an adequate story for industrial age companies for which investments in long-term capabilities and customer relationships were not critical for success. These financial measures are inadequate, however, for guiding and evaluating the journey that organizations must make to create future value through investment in customers, suppliers, employees, processes, technology, and innovation."*

The balanced scorecard (Figure 9.3) identifies four perspectives from which to view a process or an organization. These are:

- Learning and Growth Perspective
- Business Process Perspective
- Customer Perspective
- Financial Perspective

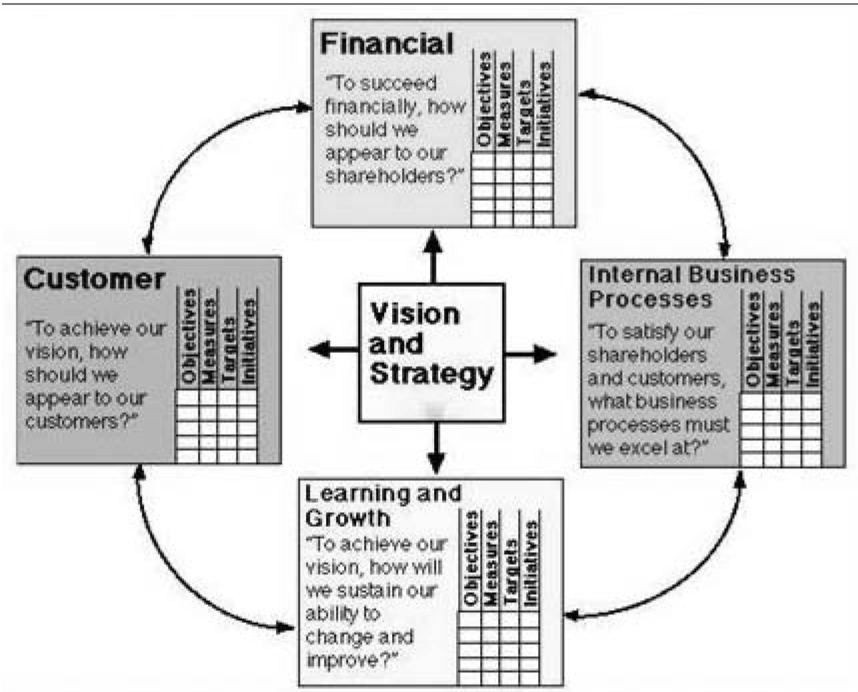

Figure 9.3 The Balanced Scorecard.

The balanced scorecard is a strategic planning and management system that is used extensively in business and industry, government, and nonprofit organizations worldwide. It helps to align business activities to the vision and strategy of the organization, improve internal and external communications, and monitor organization performance against strategic goals. It provides a balanced view of organizational performance.

The balanced scorecard has evolved from its early use as a simple performance measurement framework to a full strategic planning and management system. The "new" balanced scorecard transforms an organization's strategic plan from an attractive but passive document into the marching orders for the organization on a daily basis. It provides a framework that not only provides performance measurements, but helps organizations to identify what should be done and measured. It enables executives to truly execute their strategies.

The Learning and Growth Perspective

This perspective includes employee training and corporate cultural attitudes related to both individual and corporate self-improvement. In a knowledge-worker organization, people — the only repository of knowledge — are the main resource. In the current climate of rapid technological change, it is becoming necessary for knowledge workers to be in a continuous learning mode. Government agencies often find themselves unable to hire new technical workers. At the same time, there is a decline in training of existing employees. This is a leading indicator of a "brain drain" that must be reversed. Metrics can be put into place to guide managers in focusing training resources where they can help the most.

Kaplan and Norton emphasize that "learning" is more than "training." It also includes things like mentors and tutors within the organization, as well as ease of communication among workers that allows them to readily get help on a problem when it is needed. It also includes technological tools; what the Baldrige criteria calls "high performance work systems." In maintenance area, these tools include the use of new technologies e.g., Ultrasonic, Infrared Thermography, Motor Current Analysis, applying RCM in new design.

Maintenance &Reliability (M&R) related examples of this prospective are:

- Hours (or dollars) spent on training per person; i.e., 80 hours/person in a given year
- Percent of training hours per total; i.e., 5% in year 2009
- Number of technical papers presented or written/$M of M&R budget

- Percent of employees certified in Condition Based Maintenance (CBM) technologies or Certified Maintenance Reliability Professionals (CMRP)
- Percent of work orders created by CBM/Predictive Maintenance (PdM) technology
- Percent of CBM tasks in overall Preventive Maintenance (PM) program
- Percent of FMEA/RCM processes applied to new designs

The Business Process Perspective

This perspective refers to internal business processes. Metrics based on this perspective allow the managers to know how well their business is running, and whether its products and services conform to customer requirements (the mission). These metrics have to be carefully designed by those who know these processes most intimately. Usually with missions unique to each organization, these metrics are developed by the organizations themselves without the help of outside consultants.

In addition to the strategic management process, two kinds of business processes may be identified: a) mission-oriented processes, and b) support-oriented processes. Many processes in government, such as DoD / NASA, are mission-oriented processes, and have many unique problems in measuring them. The support processes are more repetitive in nature. Hence, they are easier to measure and benchmark using generic metrics.

Maintenance & Reliability (M&R) related examples of this perspective include:

- PM Backlog — Percent or Number of Tasks
- Scheduling Compliance — Percent
- Percent Rework
- Percent Reliability (or MTBF) — Asset / System
- Percent Material Delivered or Available on Time

The Customer Perspective

Recent management philosophy has shown an increasing realization of the importance of customer focus and customer satisfaction in any business. These are leading indicators: if customers are not satisfied, they will eventually find other suppliers that will meet their needs. Poor performance from this perspective is thus a leading indicator of future decline, even though the current financial picture may look good. For maintenance organizations, their customers are the operations. If they are not happy with the service due to increasing failure rate and downtime, they could outsource the maintenance.

In developing metrics for satisfaction, customers should be analyzed in terms of kind of customers and the kind of processes for which the organization is providing a product or service to those groups. M&R related examples of this perspective include:

- Percent downtime
- Percent availability
- Percent delivery on time (asset/system back to operation as promised)
- Customer satisfaction with the services maintenance pro vides, such as turn-around (no cost overruns, worked right the first time, asset operates at 100% performance, etc.)

The Financial Perspective

Kaplan and Norton do not disregard the traditional need for financial data. Timely and accurate financial data will always be a priority, and managers will do whatever necessary to provide it. In fact, often there is more than enough handling and processing of financial data. With the implementation of a corporate database, it is hoped that more of the processing can be centralized and automated. But the point is the current emphasis on financials leads to an unbalanced situation with regard to other perspectives.

There are two general types of measures that affect the financial outcome of a business: effectiveness and efficiency. An organization may be effective in safely producing a good product on-time, but can be outflanked by a more efficient competitor. The reverse is also true, i.e., producing in a efficient manner but without the quality expectations. Generally, the effective measures are mastered first, followed by efficiency measures. It is the old struggle between quality and production.

There is perhaps a need to include additional financial-related data, such as risk assessment and cost-benefit data, in this category. M&R related examples of this perspective are :

- Maintenance cost per unit of product or service provided
- Maintenance cost as percent of Replacement Asset Value (RAV)
- Inventory turns (of MRO store)
- MRO store Inventory as a percent of RAV
- Maintenance cost / HP installed

9.3 Benchmarking and Benchmarks

What Is Benchmarking?

Benchmarking is the process of identifying, sharing, and using knowledge and best practices. It focuses on how to improve any given business process by exploiting topnotch approaches rather than merely measuring the best performance. Finding, studying, and implementing best practices provide the greatest opportunity for gaining a strategic, operational, and financial advantage.

Informally, benchmarking could be defined as the practice of being modest enough to admit that others are better at something, and wise enough to try to learn how to match, and even surpass them. Benchmarking is commonly misperceived as simply number crunching, site briefings and industrial tourism, copying, or spying. It should not to be taken as a quick and easy process. Rather, benchmarking should be considered an ongoing process as a part of continuous improvement. Benchmarking initiatives help to blend continuous improvement initiatives and breakthrough improvements into a single change management system. Although benchmarking readily integrates with strategic initiatives such as continuous improvement, re-engineering, and total quality management, it is also a discrete process that delivers value to the organization on its own.

Types of Benchmarking

Generally there are two types of benchmarking activities. They include;

1. Internal
2. External
    a. Similar industry
    b. Best Practice

Internal Benchmarking

Internal benchmarking typically involves different processes or departments within a plant or organization. This type of benchmarking has some advantages such as ease of data collection and comparison —some of the enablers such as employee's skill level and culture would be generally similar. However, the major disadvantage of internal benchmarking is that it is unlikely to result in any major breakthrough in improvements.

External Benchmarking

External benchmarking is performed outside of an organization and compares similar business processes or best in any industry.

Similar industry benchmarking uses external partners in a similar industry or with similar processes; it shares their practices and data. This process may be difficult in some industries, but many organizations are open to share non-proprietary information. This type of benchmarking initiative usually focuses on meeting a numerical standard rather than improving any specific business process. Small or incremental improvements have been observed in this type of benchmarking.

Best Practices benchmarking focuses on finding the best or leader in a specific process and partnering with them to compare their practices and data.

Benchmarking Methodology

One of the essential elements of a successful benchmarking initiative is to follow a standardized process. Choosing an optimal benchmarking partner requires a deep understanding of the process being studied and of the benchmarking process itself. Such understandings are also needed to properly adapt best practices and implement changes to each organization's unique culture. Simply stated, the best practice needs to be tailored to meet an organization's culture if it is be implemented successfully. This dynamic process often involves finding and collecting internal knowledge and best practices, sharing and understanding those practices so they can be used, and adapting and applying those best practices in new and existing situations to enhance performance levels.

The following steps are recommended for successfully implementing a benchmarking initiative:

1. Conduct Internal analysis
2. Compare data with available benchmarks
3. Identify gaps in a specific area
4. Set objectives and define scope
5. Identify benchmarking partners
6. Gather information
   a. Research and develop questionnaire
   b. Plan benchmarking visits
7. Distill the learning — compile results
8. Select practice to implement
9. Develop plan and implement improvements — tailored practice
10. Review progress and make changes if necessary

Challenges in Benchmarking: The Code of Conduct

Benchmarking can create potential problems, ranging from simple misunderstandings to serious legal problems. To minimize the likelihood of these types of difficulties, it is strongly recommend that the benchmarking teams follow a simple Code-of-Conduct.

Legal

Don't enter into discussions or act in any way that could be construed as illegal, either for you or your partner. Potential illegal activities could include a simple act of discussing costs or prices, if that discussion could lead to allegations of price fixing or market rigging.

Be Open

Early in your discussion, it helps to fully disclose your level of expectations with regard to the exchange.

Confidentiality

Treat the information you receive from your partners with the same degree of care that you would for information that is proprietary to your organization. You may want to consider entering a non-disclosure agreement with your benchmarking partner.

Use of Information

Don't use the benchmarking information you receive from a partner for any purpose other than what you have agreed to.

The Golden Rule of Benchmarking

Treat any benchmarking partners and their information the way you'd like them to treat you and your information.

Lack of Standardized Definitions

One of the challenges in M&R benchmarking process is the absence of standardized definition of M&R terms, including metrics. We have found from our own experience that usually during the benchmarking process, the benchmarking partners spend considerable time learning to understand each other's terms, including metrics, as well as what data goes in to satisfy that specific metric. To overcome this challenge, the Society of Maintenance & Reliability Professionals (SMRP), has taken the initiative to define and standardize M&R terms. SMRP team has undertaken a very rigorous and time-consuming development process to standardize maintenance and reliability-related terms, and to obtain feedback from the M&R community to ensure their validity.

Society for Maintenance & Reliability Professionals (SMRP) Initiative

SMRP's effort is being carried out by its Best Practices committee. The committee has been developing definitions for key M&R performance metrics. Through group consensus and an extensive review by subject matter experts, including the use of web-based surveys, these metrics are becoming industry standards. As such, they can be used in benchmarking processes and when searching for best practices. This would help to create a common language in M&R field which is badly needed now.

The development process used by the SMRP Best Practices committee is a six-step process:

1. Selection of key metrics
2. Preparation of the metric descriptions
3. Review and consensus by the committee
4. Review and feedback by subject matter experts
5. Final review and editing by the committee
6. Publication

A template was also developed by the best practices / metrics team to provide a consistent method of describing each metric. The basic elements of each metric are:

- **Title:** The name of the metric
- **Definition:** A concise definition of the metric in easily understandable terms
- **Objectives:** What the metric is designed to measure or report
- **Formula:** Mathematical equation used to calculate the metrics
- **Component Definitions:** Clear definitions of each of the terms that are utilized in the metric formula
- **Qualifications:** Guidance on when to apply and not apply the metrics
- **Sample Calculation:** A sample calculation utilizing the formula with realistic values

Visit SMRP's website at www.smrp.org to view its current list of the metrics and to obtain additional information regarding best practices and metrics. Figure 9.4 is a list of metrics developed by the SMRP's Best Practices team.

#	Metric	SMRP Pillar	#	Metric	SMRP Pillar
1	Actual Cost to Planning Estimates	#5 - Work Management	36	Planner to Craft Ratio	#5 - Work Management
2	Availability	#2 - Process Reliability	37	Planning Variance Index	#5 - Work Management
3	Condition Based Maintenance Cost	#5 - Work Management	38	PM & PdM (CBM) Compliance	#5 - Work Management
4	Condition Based Maintenance Hour	#5 - Work Management	39	PM & PdM (CBM) Effectivness	#5 - Work Management
5	Continuous Improvement Man Hours	#5 - Work Management	40	PM & PdM (CBM) Work Order Backlog	#5 - Work Management
6	Contractor Manpower	#5 - Work Management	41	PM & PdM (CBM) Work Order Overdue	#5 - Work Management
7	Corrective Maintenance Cost	#5 - Work Management	42	PM & PdM (CBM) Yield	#5 - Work Management
8	Corrective Maintenance Hours	#5 - Work Management	43	Preventive Maintenance (PM) cost	#5 - Work Management
9	Craft Workers on Shift	#5 - Work Management	44	Preventive Maintenance (PM) Hour	#5 - Work Management
10	Emergency Purchase Orders	#5 - Work Management	45	Proactive Work	#5 - Work Management
11	Idle Time	#2 - Process Reliability	46	Ratio of Indirect to Direct Maintenance Personnel	#5 - Work Management
12	Inactive Stock	#5 - Work Management	47	RAV $ per Maintenance Craft Head count	# 1 - Business Management
13	Indirect Maintenance Personnel Cost	#5 - Work Management	48	Reactive Work	#5 - Work Management
14	Indirect Stock	#5 - Work Management	49	Ready Backlog	#5 - Work Management
15	Internal Maintenance Personnel Cost	#5 - Work Management	50	Schedule Compliance	#5 - Work Management
16	Maintenance Cost as % of Asset Replacement Value (RAV)	# 1 - Business Management	51	Schedule Compliance - Work Orders	#5 - Work Management
17	Maintenance Cost per unit of Production	# 1 - Business Management	52	Scheduled Downtime	#3 - Equipment Reliability
18	Maintenance Margin	# 1 - Business Management	53	Standing Work Orders	#5 - Work Management
19	Maintenance material Cost	#5 - Work Management	54	Stock Outs	#5 - Work Management
20	Maintenance Shutdown Cost	#5 - Work Management	55	Store Value as % of RAV	# 1 - Business Management
21	Maintenance Training Cost as % of Total	#4- People Skills	56	Storeroom Records	#5 - Work Management
22	Maintenance Training Hours as % of Total	#4- People Skills	57	Storeroom Transactions	#5 - Work Management
23	Maintenance Training ROI	#4- People Skills	58	Stores Inventory Turns	#5 - Work Management
24	MDT	#3 - Equipment Reliability	59	Supervisor to Craft Ratio	#5 - Work Management
25	MTBF	#3 - Equipment Reliability	60	Systems covered by Criticality Analysis	#3 - Equipment Reliability
26	MTBM	#3 - Equipment Reliability	61	Total Downtime	#3 - Equipment Reliability
27	MTTF	#3 - Equipment Reliability	62	Total Operating time ratio	#2 - Process Reliability
28	MTTR	#3 - Equipment Reliability	63	Unplanned Work	#5 - Work Management
29	OEE	#2 - Process Reliability	64	Unscheduled Downtime	#3 - Equipment Reliability
30	OEE - 24x7	#2 - Process Reliability	65	Uptime	#2 - Process Reliability
31	Overtime Maintenance Cost	#5 - Work Management	66	Utilization Rate	#2 - Process Reliability
32	Overtime Maintenance Hours	#5 - Work Management	67	Vendor Management Stock	#5 - Work Management
33	Planned Backlog	#5 - Work Management	68	Work Order Aging	#5 - Work Management
34	Planned Work	#5 - Work Management	69	Work Order Cycle	#5 - Work Management
35	Planner Effectiveness	#5 - Work Management	70	Wrench Time	#5 - Work Management

Figure 9.4 SMRP Metrics

A few examples of standardized metrics developed by the SMRP best practices team, of which the author has been a member, are shown in Appendix 9-A with details on page 269.

Benchmarks

A benchmark refers to a measure of best practice performance whereas benchmarking refers to the actual search for the best practices. Emphasis is then given to how we can apply the process to achieve superior results. Thus, a benchmark is a standard, or a set of standards, used as a point of reference for evaluating performance or quality level. Benchmarks may be drawn from an organization's own experience, from the experience of others in the industry, or from regulatory requirements such as those from Environmental Protection Agency (EPA) or Occupational Safety and Health Agency (OSHA).

If we were to benchmark world conquest, what objective measure would we use to compare Julius Caesar to Alexander the Great, or Genghis Khan to Napoleon? Which of them was the epitome, and why? We do the same thing in business. Which organization has the best PdM? Who provides the most responsive customer service department? Who is the best in planning/scheduling? What about the leanest manufacturing operation? And how do we quantify that standard?

Figure 9.5 lists some of the key maintenance and reliability best practices benchmarks.

9.4 Data Collection and Quality

Another key challenge in performance measurement system is data collection and availability of quality data on a timely basis. Data is the key ingredient in performance measurement. Major factors in establishing a performance measurement system are:

a. Cost of data collection
b. Data quality
c. Data completeness
d. Extrapolation from partial coverage
e. Matching performance measures to their purpose
f. Understanding extraneous influences in the data
g. Timeliness of data for measures
h. Use of measures in allocation of funding
i. Responsibility for measures, and limited control over the process
j. Benchmarking and targets

Maintenance and Reliability Best Practices Key Benchmarks:

	Quartile I	II	III	IV
Plant /Organization/ Process				
Maintenance Costs as % RAV	< 2.5	2.5% -3.0%	3.0% -5.0%	>5.0%
Maintenance Costs per Unit Output		*Varies by Production Unit (5 – 15 %)*		
Return on Net Assets (RONA)		*Varies by Organization*		
Percentage Overtime	< 5 %	5 – 10 %	10 – 20 %	> 20 %
Training Hours /Person	> 80	48 - 80	20 – 48	< 20
Safety Performance – OSHA Injuries/200K Hours	< 0.5	0.5 – 1	1-3	> 3
Overall Asset / System / Process				
Availability	> 97%	95%-97%	95%-80%	< 80%
Downtime as % of Total Scheduled (Operating) Hours	< 1 %	1 – 3 %	3 – 5%	> 5 %
Overall Equipment Effectiveness (OEE)	> 80 %	70 - 80 %	40– 60 %	< 40 %
Planning & Scheduling and MRO Store				
Reported Hours in CMMS as % of Total Paid Hours	> 99%	95%-99%	80%-95%	< 80%
Work Hours Expended on Blanket Work Orders as % of Total	< 10%	10%-20%	20%-30%	> 30%
Planned Work as % of Total Work	> 85%	75%-85%	65%-75%	< 65%
Planning Accuracy (Estimated Hours to Actual Hours)	Estimate ± 10%	Estimate ± 15%	Estimate ± 20%	Estimate ± 25%
Schedule Compliance in %	> 90%	75%-90%	60%-75%	< 60%
Reactive Work (Emergency, Break-in Work) as % of Total	< 10%	10%-20%	20%-30%	> 30%
Labor Effectiveness (Wrench Time) in %	> 60%	50%-60%	30%-50%	< 30%
Rework (Poor Quality) Hours in % of Total Work Hours	< 2%	2%-5%	5%-10%	> 10%
Work Orders Closed with Comments – Data Quality	> 95%	80%-95%	60%-80%	< 60%
Inventory Turns (MRO store)	> 2	1.5 – 2	1 – 1.5	< 1
Inventory Accuracy - %	> 98 %	95 – 98 %	90 – 95 %	< 90 %
Maintenance, Preventive & CBM/PdM				
Preventive and CBM/PdM Hours as % of Total Hours	60%	40–60%	20–40%	< 20%
Preventive and CBM/PdM Schedule Compliance	> 95%	90%–95%	75%–90%	< 75%
Work Created by PM & CBM/PdM as % of Total Hours	> 25 %	20 – 25 %	10 – 20 %	< 10 %
Root Cause Failure Analysis (RCFA) Performed for Failures	> 95%	80%–95%	60%–80%	< 60%
Reliability Program				
Mean Time between Failure / Repair –MTBF/MTTR tracked	*Varies by organization and types of assets*			
Faults detected prior to failure	>95%	80% – 95%	50% – 80%	< 50%
Failures due to lubrication % of total	0%	< 5%	5% – 20%	20%
FMEA/RCM based PM plan % of total assets /systems	> 60%	40 – 60%	10 – 30%	< 10%

Note: Benchmarks based on the author's experience, surveys and available literature. Benchmark will vary with type of industry, organizations and with time.

Figure 9.5

Evidently, an efficient and effective data collection system is needed to ensure availability of quality data. A data collection system should :

1. Identify what data needs to be collected and how much; the population from which the data will come, and the length of time over which to collect the data.
2. Identify the charts and graphs to be used, the frequency of charting, various types of comparison to be made, and the methodology for data calculation.
3. Identify the characteristics of the data to be collected. (Attribute data are items that can be counted — variable data are items that can be measured.)
4. Identify if existing data sources can be utilized or new data sources need to be created for new or updated measure of performance. All data sources need to be credible and cost effective.

How good are metric(s)? The following questions may serve as a checklist to determine the quality of metrics and to develop a plan for improvement:

- Do the metrics make sense? Are they objectively measurable?
- Are they accepted by and meaningful to the customer?
- Have those who are responsible for the performance being measured been fully involved in the development of this metric?
- Does the metric focus on effectiveness and/or efficiency of the system being measured?
- Do they tell how well goals and objectives are being met?
- Are they simple, understandable, logical, and repeatable?
- Are the metrics challenging but at the same time attainable?
- Can the results be trended? Does the trend give useful management information?
- Can data be collected economically?
- Are they available timely?
- Are they sensitive? (Does any small change in the process get reflected in the metric?)
- How do they compare with existing metrics?
- Do they form a complete set — a balanced scorecard (e.g., adequately covering the areas of learning and growth, internal business process, financial, and customer satisfaction)?
- Do they reinforce the desired behavior — today and in the long haul?

- Are the metrics current (living) and changeable? (Do they change as the business changes?)

9.5 Summary

Performance measurement is a means of assessing progress against stated goals and objectives in a way that is quantifiable and unbiased. It brings with it an emphasis on objectivity, consistency, fairness, and responsiveness. At the same time, it functions as a reliable indicator of an organization's health. Its impact on an organization can be both immediate and far-reaching.

Performance measurement asks the question, "What does success really mean?" It views accomplishment in terms of outputs and outcomes, and it requires us to examine how operational processes are linked to organizational goals. If implemented properly, performance measures — metrics — are evaluated not on the basis of the amount of money that is spent or the types of activities performed, but on whether organization has produced real, tangible results.

The real objective of metrics should be to change the behavior so that people do the right things. The secondary objective is to determine the health of the process or assets being monitored. A metric is nothing more than a standard measure to assess performance in a particular area. However there is an imperative need to ensure that right things are being measured.

Performance indicators can be leading or lagging. The purpose of using these indicators is to measure the performance of the process or asset and to help identify where the process is working well and where it is not. Leading and lagging indicators provide information so that positive trends can be reinforced and unfavorable trends can be corrected through process changes. Leading indicators measure the process and predict changes and future trends. Lagging indicators measure results and confirm long-term trends. Whether an indicator is a leading or lagging indicator depends on where in the process the indicator is applied. Lagging indicators of one process component can be a leading indicator of another process component.

A benchmark is a measure of best practice performance. Benchmarking refers to the search for the best practices that yields the benchmark performance, with emphasis on how can we implement the best practice to achieve superior results.

Finally, developing a performance measurement system that provides feedback relative to an organization's goals and supports it in achieving these goals efficiently and effectively is essential. A successful performance measurement system should:

- Comprise a balanced set of a limited vital few measures
- Produce timely and useful reports at a reasonable cost
- Disseminate and display information that is easily shared, understood, and used by all in the organization
- Help to manage and improve processes and document achievements
- Support an organization's core values and its relationship with customers, suppliers, and stakeholders

9.6 References and Suggested Reading

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Appendix 9A- DRAFT

SMRP Best Practice Metrics **Business & Management**

1.5 Annual Maintenance Cost As a Percent of Replacement Asset Value (RAV)

A. Definition:

The metric is the amount of money spent annually maintaining assets, divided by the Replacement Asset Value (RAV) of the assets being maintained, expressed as a percentage.

B. Objectives:

This metric allows one to compare the expenditures for maintenance with other plants of varying size and value, as well as to benchmarks. The RAV as the denominator is used to normalize the measurement given that different plants vary in size and value.

C. Formula:

$$\text{Annual Maintenance Cost per RAV (\%)} = \frac{\text{Annual Maintenance Cost (\$)}}{\text{Replacement Asset Value (\$)}} \times 100$$

D. Component Definitions

Annual Maintenance Cost	Annual expenditures for maintenance labor (including maintenance performed by operators, e.g., TPM), materials, contractors, services, and resources. Include all maintenance expenses for outages/shutdowns/turnarounds as well as normal operating times. Include capital expenditures directly related to end-of-life machinery replacement (this is necessary so that excessive replacement – vs. proper maintenance – is not masked). Do not include capital expenditures for plant expansions or improvements. Ensure maintenance expenses included are for the assets included in the RAV in the denominator. Maintenance costs are for activities on work orders. (i.e., tie to work order)
Replacement Asset Value (RAV)	Also referred to as Estimated Replacement Value (ERV). The dollar value that would be required to replace the production capability of the present assets in the plant. Include production/process equipment as well as utilities, support and related assets. Do not use the insured value or depreciated value of the assets. Include replacement value of buildings and grounds if these assets are maintained by the maintenance expenditures. Do not include value of real estate – only improvements.

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Prepared by: Robert DiStefano Date: December 8, 2007

DRAFT

1.5 Annual Maintenance Cost As a Percent of Replacement Asset Value (RAV)

E. Qualification:

1. Should be measured annually.
2. Typically used by corporate managers to compare plants, by plant managers, maintenance managers, operations managers, reliability managers, vice presidents.
3. Can be used to determine standing of a plant in a four-quartile measurement system, as best in class plants with high asset utilization and high equipment reliability in most industries spend less money maintaining their assets.
4. Cannot rely on this metric alone, since lower maintenance cost does not necessarily equate to best in class.

F. Example Calculation:

If Maintenance Spend is $3,000,000 annually, and the Replacement Asset Value (RAV) is $100,000,000, then the Annual Maintenance Cost as a Percent of RAV would be:

$$\text{Annual Maintenance Cost per RAV (\%)} = \frac{\text{Annual Maintenance Cost (\$)}}{\text{Replacement Asset Value (\$)}} \times 100$$

$$= [\$3{,}000{,}000/\$100{,}000{,}000] \times 100$$

$$= 3\%$$

SMRP Metric 1.5 and its supporting definitions are similar or identical to the indicator E1 in standard EN 15341

This document is recommended by EFNMS as a guideline/supporting document for the calculation of the E1 indicator.

Appendix 9B- DRAFT

SMRP Best Practice Metrics **Equipment Reliability**

3.5.1 Mean Time Between Failures (MTBF)

A. Definition:

Mean Time Between Failures (MTBF) is the average length of time between one failure and another failure for an asset or component. MTBF is usually used for repairable assets of similar type. Another term, Mean Time to Failure (MTTF) is usually used for non-repairable assets, i.e., light bulbs, rocket engines etc. Both terms are used as a measure of asset reliability. These terms are also known as mean life. MTBF is the reciprocal of the Failure Rate (λ), at constant failure rates.

B. Objectives:

This metric is used to assess the reliability of an asset. Reliability is usually expressed as the probability that an item or asset will perform its intended function without failure for a specified time period under specified conditions.

An increasing MTBF indicates improved asset reliability

C. Formula:

MTBF = Operating time (hours) / Number of Failures

D. Component Definitions

Failure	The inability of an asset to perform its required function. This excludes proactive repairs.
Operating Time	A particular interval of time during which the item or asset is performing its required function.

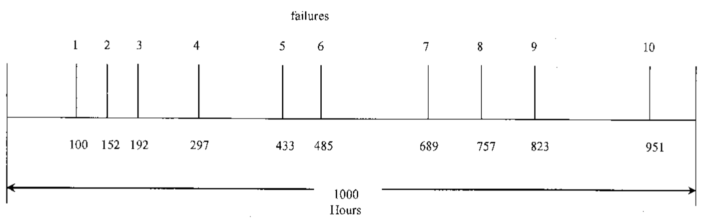
E. Qualification:

1. Time Basis: Equipment dependent
2. To be used by: maintenance personnel and reliability engineers
3. Best when used at asset or component level.
4. This metric should be performed on critical assets and trended over time.
5. Can be used to compare reliability of similar equipment types.
6. For low MTBF numbers, analysis should be performed (i.e., root cause failure analysis (RCFA), failure mode and effects analysis (FMEA)) in order to determine how the asset's reliability can be improved..
7. By using MTBF as a parameter for redesign, the repair time and maintenance cost for an asset could be reduced after it has been in operation.

3.5.1 Mean Time Between Failures (MTBF)

E. Sample Calculation:

If an asset had 10 failures in 1000 hours of operation, as indicated in the diagram below,



then the Mean Time Between Failures is

MTBF = Operating time (hours) / Number of Failures

MTBF = 1000 hours / 10 failures = 100 hours

SMRP Metric 3.5.1 and its supporting definitions are similar or identical to the indicator T17 in standard EN 15341

This document is recommended by EFNMS as a guideline/supporting document for the calculation of the T17 indicator.

Chapter 10

Workforce Management

What I hear, I forget. What I see, I remember. What I do, I understand.
— Kung Fu Tzu (Confucius)

After reading the chapter, the reader will be able to understand:

- Deming's view to improve organizational effectiveness
- Employee life cycles
- People development-related issues
    - Aging Workforce
    - Diversity
    - Generation gap
    - Training types and benchmarks
- Challenges in managing the workforce

10.1 Introduction

People make it happen. They get things done. We may have great plans and the best processes, but if we don't have the people available with the right skills, these plans and processes can't be implemented or carried out effectively. Developing people — the workforce — and empowering them to give their best is key to defining the difference between an ordinary company and a great organization. Of course, the processes must be in place to nurture and harness the potential of human capital.

The maintenance and reliability processes are no different than any other processes in any industrial set-up. Organizations that are considered to be the "Best of the Best" or "World Class" use many of the same key principles. Dr. W. Edwards Deming, the world renowned expert in the field of quality, gave us the following 14 nuggets of wisdom which any organization can use to improve its effectiveness.

1. Create constancy of purpose towards improvement.

Replace short-term reaction with long-term planning. Aim to become competitive and stay in business.

2. Adopt the new philosophy.

We are in a new economic age. Management must awaken to the challenge, must learn their responsibilities, and take on leadership for change rather than merely expect the workforce to do so.

3. Cease dependence on inspection.

If variation is reduced, there is no need to inspect manufactured items for defects, because there won't be any. Build quality into the product in the first place. Inspection is not a value-added activity.

4. End the practice of awarding business on the basis of price tag (minimum cost).

Move towards a single supplier for any one item. Multiple suppliers mean variation between feedstocks. Build a long-term relationship and trust with suppliers.

5. Improve constantly and forever.

Strive constantly to improve the system of production and service, to improve quality and productivity, and thus constantly to decrease costs.

6. Institute training on the job.

If the people — the workforce — are not adequately prepared and trained to do the job right, they will introduce variation and defects. New skills are required to keep up with changes in materials, methods, products, and services.

7. Institute leadership.

There is a distinction between leadership and mere supervision. The latter is quota and target based. The aim of supervision should be to help people and machines and gadgets to perform a better job.

8. Drive out fear.

Deming sees management by fear as counter-productive in the long term because it prevents people from acting in the organization's best interests.

9. Break down barriers between departments.

All in the organization working in research, design, sales, operations /production, and maintenance must work as a team, to foresee problems of production and customer satisfaction that may be encountered with the product or service. The organization should build the concept of the internal customer that each department serves — not the management, but the other departments that use its outputs.

10. Eliminate slogans and exhortations.

It's not people who make most mistakes; it's the process they are working within. Eliminate the use of slogans, posters, and exhortations for the work force, demanding zero defects or zero breakdowns and new levels of productivity, without providing improved methods. Harassing the workforce without improving the processes they use is counter-productive.

11. Eliminate arbitrary numerical targets.

Eliminate work standards that prescribe quotas for the work force and numerical goals for people in management. Substitute aids and helpful leadership in order to achieve continual improvement of quality and productivity.

12. Permit pride of workmanship.

Remove the barriers that rob people of the pride of workmanship.

The responsibility of managers, supervisors, and foremen must be changed from sheer numbers to quality. Allow employees to see their end product. Doing so creates ownership and helps to generate new ideas for improvement.

13. Institute education and self-improvement.

Institute a vigorous program of education, training, and encouraging self improvement for everyone. What an organization needs is not just good people; it needs people who are improving with education. Advances in competitive position in the market place will have their roots in knowledge.

14. The transformation is everyone's job.

Create a structure in top management that will push every day on the preceding points. Take action in order to accomplish the transformation. Support is not enough; action is required. Put everybody in the organization to work to accomplish the transformation.

Most of Dr. Deming's principles relate to the workforce, including management and their role in acquiring, preparing, and educating the workforce as well as improving the processes to get productivity gains. These points can be applied from small organizations to large ones, from the service industry to manufacturing.

In this chapter, we will be discussing people — the workforce. What do we need to do to hire the right people, prepare them with the right skill sets, and then retain them to perform their job effectively? This topic is very important and challenging in today's global economy and demographically diverse workforce.

10.2 Employee Life Cycle

An employee life cycle covers the steps employees go through from the time they are hired in an organization until they leave. Human Resource professionals often focus their attention on the steps in this process in hopes of making an impact on the organization's bottom line. Normally, their goal is to reduce the organization's cost per employee hired, which theoretically is a good thing. Unfortunately, they aren't the ones who can make them stay willingly and be productive with the organization. However, the managers for whom newly hired employees are going to work can make the real difference.

On a practical day-to-day basis, employees don't really work for an organization; they work for somebody — a boss. To the extent that we can be good bosses, we can keep employees motivated, happy, and productive, and reduce the costs associated with employee turnover. In turn, we can make our jobs easier and increase value to the organization.

Employees are one of an organization's largest expenses these days. Unlike other major capital costs such as buildings, machinery, and technology, human capital is highly volatile. Managers are in a key position to reduce that volatility by reducing the overall life cycle cost of employees in the organization. This life cycle consists of four steps:

- Hire
- Inspire
- Admire
- Retire

Hire

This first step is probably the most important. It is important to hire the best people we can find. This is not a time to be cheap. The cost of replacing a bad hire far exceeds the marginal additional cost of hiring the best person in the first place. Hire talent, not just trainable skills. Skills can be taught to a talented employee.

Make your organization a place people want to come to and work for. An organization's culture can be a powerful recruiting tool. Ensure that the new hire understands the goals your department or organization wants to achieve.

Inspire

Once we have recruited the best employees to come to work on our team, the hard part begins. We have to inspire them to perform to their best abilities. We have to challenge and motivate them. That is where we will get their best effort and creativity that will help the organization excel.

Make them welcome. Make them feel like part of the team from day one. Set goals for them that are hard, but achievable. Be a leader, not just a manager. It is a good practice to assign a mentor to help them get acquainted with the new environment.

Admire

Once we have hired the best employees and have challenged and motivated them, our job to inspire them continues. The biggest mistake is made when a manager ignores them. As soon as we start to slack off, their satisfaction and motivation decreases. If we don't do something, they will become disenchanted and will leave. They will become part of the "employee turnover" statistics that need to be avoided.

We want TGIM (thank goodness, it's Monday) employees, not TGIF (thank goodness, it's Friday) ones.

Give employees positive feedback as much as possible, even if it's just a few good words. Provide appropriate rewards and recognition for jobs done well. Provide them additional training to develop new skill sets.

Retire

The time when somebody retires after a long service is when we know that we have been successful. When employees see the organization as the employer of choice, they will come and work for us. When they recognize us as a good boss and a real leader, they will stay around. As long as we continue to inspire, motivate, and challenge them, they will continue to contribute at the high levels the organization's needs in order to beat the competition. They will be long-term employees; even staying with the organization until they retire. They will refer other quality employees, including their relatives. Organizations will attract and retain second and even third generation loyal employees.

Along the way, the organization will have had some of the most creative and productive employees with the lowest employee costs in the market.

10.3 Understanding the Generation Gap

There is a shortage of skilled industrial workers, the people who operate and maintain sophisticated assets / systems on the plant floor, as well as engineering and management professionals. This shortage poses a serious threat to our industrial competitiveness. The shortage lies in the demographics as most veterans have left the work place and baby boomers are getting close to their retirement. Predominately four generations of workers co-exist in today's workplace. The following list reflects William Strauss and Neil Howe's organization from their book *Generations*:

Silent	Born between 1925–1942
Baby Boom	Born between 1943–1960
Generation X	Born between 1961–1981
Generation Y	Born between 1982 – 2001

The differences between the generations create many challenges in the workplace. These challenges, which can be negative or positive, often relate to variations in perspective and goals as a result of generational differences. This area gets further complicated because of the age differences between managers and employees. Organizations can't assume that people of varying ages will understand each other or have the same perspective and goals. In order to be successful, there is a need to understand and value the generational differences and perspectives and turn those negatives into positives.

Some of the each group's talent and most common differences between the generations are:

Silent

The Silent generation are adaptive in nature and have a very intense sense of loyalty and dedication. They are also known as Traditionalist. Many of them have been puppets, paupers, or pirates. As a result, they have a wealth of knowledge to contribute to any organization. Many in this group are not leaving the workforce yet. It is important to note that some either can't leave due to financial reasons. Others love their work, are still in good health, and want to continue to contribute to the organization.

The work ethic of the Silent Generation is built on commitment, responsibility, and conformity as tickets to success. Most came of age too late to be the heroes of World War II, yet too early to participate in the youthful rebelliousness of the 1960s "Consciousness Revolution." On the job, they are not likely to "rock the boat," break the rules, or disrespect authority. Tempered by war, a command and control approach comes naturally.

The challenge for leaders is how to empower Silent employees — to find out what motivates them and then tailor the job to each individual's needs. They still want respect for contribution and longevity. It's also crucial that leaders don't let them think that their time has come, that they should go. They have a loyalty and commitment that is increasingly hard to find in younger employees.

It would be very beneficial for the organization to team up a seasoned Silent employee with a Generation Xer or Yer on a project to foster knowledge transfer both ways. Veterans bring the institutional and historical experience whereas Xers and Yers often bring the technological and innovational savvy. Also, Silent employees can be trained in new technology. Some leaders believe that training them on new technology or process is a bad investment due to their age. It is wrong thinking. They are hard working and can be trained easily.

Baby Boomers

Boomers, idealists in nature, have always been seen as loyal to their organizations. They feel a sense of belonging and dedication based on their history. The Baby Boom Generation changed the physical and psychological landscape forever. As products of "the Wonder Years," they were influenced by the can-do optimism of John F. Kennedy and the hope of the post-World War II dream. But the intense social and political upheaval of Vietnam, assassinations, and civil rights, led them to rebel against conformity and to carve a perfectionist lifestyle based on personal values and spiritual growth. They welcome team-based work, especially as an anti-authoritarian declaration to "The Silents" ahead of them, but they can become very political when their turf is threatened. Rocked by years of reorganizing, reengineering and relentless change, they now long to stabilize their careers.

One of the most common complaints Boomers make about Gen Xers and Gen Yers is that "they don't have the same work ethic." This does not mean that they are not hardworking employees, but it does mean that they place a different value and priority on work.-

Boomers are motivated by:

- **Power and prestige.** Boomers are often traditionalists, and perks of the position matter. They want titles and authority commensurate with responsibility.
- **Networking and Learning.** Boomers want to participate in associations and conventions that keep them professionally connected to their peers. Boomers are motivated by working together on professional projects in affiliation with others like them.
- **Long Term Benefits.** Boomers are interested in compensation that is more long term, such as profit sharing and health care benefits including long-term care.

Generation (Gen) Xers

In general, Gen Xers are those born during the 1960s and 1970s. This generation, therefore, includes a range of employees in their thirties and forties.

The Gen Xers, often-maligned, so named because no one could settle on an accurate definition, are characterized by an economic and psychological "survivor" mentality. They grew up very quickly amid rising divorce rates, latchkeys, violence, and low expectations. They entered the job market in the wake of the Boomers, only to be confronted with new terms like "downsizing" and "RIFs" as the economy plunged into recession. It's hardly surprising, then, that they tend to be skeptical toward authority and cautious in their commitments. Their self-reliance has led them, in unprecedented numbers, to embrace "free agency" over organization's loyalty. Ambitious and independent, they're now striving to balance the competing demands of work, family, and personal life.

Gen Xers bring new challenges as well as new ideas into the labor market. They want and demand benefits such as stock option plans, health care insurance, and time off (paid vacation, sick days, personal leave days). They tend to be less motivated by promises of overtime pay and more motivated by personal satisfaction with their jobs. The number one benefit for Generation Xers is development and training. They want to grow in their jobs and learn new skills.

Gen Xers do not anticipate staying with one job or company throughout their entire career. They have seen their parents laid off. Many of them have grown up in divorced family situations. They expect to change jobs as they seek employment that offers them both better benefits and more opportunity for professional growth as well as personal fulfillment. They want, and expect, their employers to hear what they have to say. They have an interest in understanding the "big picture" for the organization and how this influences their employment and growth. They are less likely to accept a "because I said so" attitude from a supervisor.

Some of the ways to motivate Gen Xers to maximize productivity:

Take time to be personal.

Thank an employee for doing a good job in person, in writing, or both. Listen to what employees have to say, both in a one-on-one situation and in a group meeting.

Encourage growth.

Provide feedback on the employee's performance. Make sure the employee understands expectations. Involve them in the decision-making process whenever possible.

Provide Training.

Pay for employees to attend workshops and seminars. Provide on-site classes where employees can learn new skills or improve upon old ones. Challenge them.

Motivate through Rewards and Promotions.

Recognize employees who have done an outstanding job by giving an unexpected reward, such as a day off or a free dinner for employees and their family at a nice restaurant.

Encourage Teamwork.

Provide opportunities for collaboration and teamwork. This generation "fuels their fire" through teamwork.

Create Ownership.

Help employees understand how the business operates. They need to experience a sense of ownership. Encourage this by providing them with information about new products or services, advertising campaigns, strategies for competing, etc. Let each employee see how he or she fits into the plan and how meeting their goals contribute to meeting the organization's objectives.

Build morale.

Have an open work environment; encourage initiative, and welcome new ideas. Don't be afraid to spend a few dollars for such things as free coffee or tea for employees, or ordering a meal for employees who have to work overtime. Take time to speak with an employee's spouse or family when you meet them and let them know you appreciate the employee. Gen Xers look for more than just fair pay; they need and want personal acknowledgment and job satisfaction.

Generation (Gen) Yers

In general, Gen Yers are those born after 1980. They are also known as Echo- Boom or Millennial generation. This generation, therefore, includes a range of employees from those approaching their late 20s and all the way to older teenagers just entering the job market. Coming of age during a shift toward virtue and values, they're attracted to organizations whose missions speak to a purpose greater than a bottom line. They're technologically savvy with a positive, can-do attitude that says: "I'm here to make a difference." And they will.

To motivate Gen Yers, the following is suggested:

Work Schedule Flexibility.

Provide Gen Yers flexibility in when and where work is done. Gen Yers resist what they see as rigid workday starting times. They do not understand why coming to work 15–30 minutes late is viewed by

Boomers as irresponsible behavior.

Change and Challenges.

Gen Yers are interested in change and challenge. They will leave a higher-paying good job for the opportunity to experience something new. They do not see their careers as needing to be linear. They stay in a particular job often no more than two to three years.

Do not interpret their rebellious nature as negative. Caution! Sometime they need to vent out; let them do it. Do not take it personally. This generation will challenge and change much of what we need to change.

Although Gen Xers and Gen Yers are motivated by different things, both age groups need the following:

- Frequent communication, including being told the "why" and not just the "what" of projects and priorities.
- To be included, and not just in what affects them most directly.
- To have fun at work.

In order for an organization to be truly successful, all co-existing generations in the workplace need to understand and value each other, even when their perspectives and goals are different.

As Silents, Baby Boomers, Gen Xers and Gen Yers intersect in the workplace, their attitudes, ethics, values, and behaviors inevitably collide. Nearly 70% of participants in a recent Web poll say they're experiencing a "generational rift."

Organizations need to look beyond this clash of the generations for ways to leverage multi-generational perspectives to their benefit. If we take the time to master a few tools and strategies for communicating across generations, we'll be better positioned to tap the best that each brings to the workplace. Here are some suggestions:

- It's not what we say, but how we say it. Generational clashes often stem from miscommunications in tone or style. The Silents, for example, are aware that they might be technologically challenged; empathy is a better strategy than derision. The younger generations, in general, might have shorter attention spans than their seniors, so they may prefer verbal training to reading documents.
- Understand the different generational motives. Gen Xers may seem to be less driven, and Baby Boomers managing Gen Xers

should know that money usually isn't the motivating force. It's quality of life. We should look for ways to support Gen Xers' balanced lifestyle.
- Look beyond appearances. Benefit from diverse opinions. Keep an open mind about attitudes. Adapt style to the realities of today's workplace.

We're living through profound changes in the business world. Traversing this generational landscape, bolstered by new learning and respect for differing ideals about the workplace, will get the job done better and faster. Look for what unites us with our peers. We will be better prepared to welcome the generation that comes next.

Each generation has complained about those in other groups. So the fact that there are differences in the generations is nothing new. What is new today is the magnitude of the differences. It is time to understand and value this diversity so that we can benefit from it. Failing to do this can result in failure for everyone.

10.4 People Development

Developing people within an organization should be viewed as an investment. Then it becomes easy to understand the importance of maintaining this key resource so that it keeps performing at optimum level. If we know the cost of replacing an employee, then it is easy to conclude that getting the most from employees just makes good business sense.

But this is much easier said then done, particularly with so many diverse behaviors, motivations, and desires. How do we develop our people resources? There are several ways to help increase people satisfaction and increase productivity that will benefit the employees and the organization.

Are people performing their jobs to the best of their abilities? What additional training would allow particular employees to do their job better? (Answers may include personal development, skills training, or both.) Can job rotations or on-the-job training (OJT) with experienced coworkers enhance employees' skills and awareness of how their work fits into overall organization's goals? Could their tasks be automated, allowing people to grow in other areas? These are some of the questions we need to consider while developing a plan to enhance knowledge and skill sets of our people.

Job task analysis is one of the techniques that could be used to identify specific training needs, ensuring that employees have appropriate knowledge and skill sets to do their jobs effectively.

Job Task Analysis (JTA)

Job task analysis is the foundation of a successful training program. Before employees can be trained, we must identify what they need to learn. Job analysis is a process that determines in detail the particular duties and requirements for a given job as well as the relative importance of these duties.

A job is a collection of tasks and responsibilities that are assigned to an employee. A task is typically defined as a unit of work, that is, a set of activities needed to produce some result, e.g., changing belts, repairing a pump, delivering or expediting material, performing FMEAs, or sorting the mail. Complex positions in the organization may include a large number of tasks, which are sometimes referred to as functions. Job descriptions are lists of the general tasks, or functions, and responsibilities of a position. Typically, they also include to whom the position reports, specifications such as the qualifications needed by the person in the job, salary range for the position, etc.

Job descriptions are usually developed by conducting a job analysis, which includes examining the tasks and sequences of tasks necessary to perform the job. The analysis looks at the areas of knowledge and skills needed for the job. A role is the set of responsibilities or expected results associated with a job. A job usually includes several roles. An important aspect of job analysis is that the analysis is conducted of the job, not the person. Although job analysis data may be collected from incumbents through interviews or questionnaires, the product of the analysis is a description or specifications of the job, not a description of the person.

The purpose of job analysis is to establish and document the skills required for performing the job effectively. This can help in employment procedures such as selection of employee, compensation, performance appraisal, and training.

New Hire Selection Process / Procedures

Job Analysis can be used in selection process to identify or develop:

- Job duties that should be included in advertisements of vacant positions

- Appropriate salary level for the position to help determine what salary should be offered to a candidate
- Minimum requirements (education and experience) for screening applicants
- Interview questions
- Selection instruments (e.g., written tests; oral tests; job simulations)
- Applicant appraisal and evaluation forms
- Orientation materials for applicants and new hires

Performance Review

Job analysis can be used in performance review to identify or develop:

- Goals and objectives
- Performance standards
- Evaluation criteria
- Job duties to be evaluated
- Time period between evaluations

Determining Training Needs

Job analysis can be used to identify required knowledge and skills and to develop appropriate training, including:

- Training content
- Assessment tests to measure effectiveness of training
- Equipment to be used in delivering the training
- Methods of training (i.e., small group, computer-based, video, classroom)

Several methods may be used individually or in combination to perform job analysis. These include:

- Review of job classification systems
- Incumbent interviews and logs
- Observations
- Area supervisor interviews
- Expert panels
- Structured questionnaires
- Task inventories
- Check lists

A typical method of job analysis would be to give the incumbent a simple questionnaire to identify job duties, responsibilities, equipment used, work relationships, and work environment. The completed questionnaire would then be used to assist the job analyst, who would then conduct an interview with the incumbents. A draft of the identified job duties, responsibilities, work environment, asset and tools knowledge, and relationships would be reviewed with the supervisor for accuracy. The job analyst would then prepare a job description and job specifications. In case of a new position, the job analyst prepares the document with the help of the requester and area supervisor. Information collected by the job analyst can be grouped in the following five categories:

Duties and Tasks

The basic unit of a job is the performance of specific tasks and duties. Information to be collected about these items may include: frequency, duration, effort, skill, complexity, equipment, and standards.

Environment

The work environment may include unpleasant conditions such as temperature extremes, offensive odors, and physical limitations (or constraints) that can hinder the job performance. There may also be definite risks such as noxious fumes, X-rays and radioactive exposures, and dangerous explosives.

Tools and Equipment

Some duties and tasks are performed using specific equipment and tools. Equipment may include protective clothing. These items need to be specified in a job analysis.

Relationships

Is supervision required or not? What kind of interaction does this job require — internally with fellow employees or externally with others outside the organization?

Requirements

Knowledge, skills, and abilities (KSAs) are required to perform the job. Although an incumbent may have higher KSAs than those required for the job, a job analysis typically states only the minimum requirements to perform the job.

Skills Development Training

The skill level of the maintenance personnel in most organizations today is well below what industry would classify as acceptable. The literacy level of many maintenance personnel is becoming a challenge. New entry-level employees have shown a noticeable drop in basic math and reading skills. They have also shown a lack of interest in Operations and Maintenance related work. Moreover, many organizations have eliminated their apprenticeship programs so now they are unable to fill their own positions with qualified employees. These factors are creating a great demand for employees with acceptable level of skills.

Today's assets and systems are increasingly complex. They require an educated and skilled workforce to operate and maintain them effectively. It has been determined by several studies that today's craft person requires a minimum educational level of 12 years with additional vocational training to meet the work requirements.

Numerous studies have also shown that 70–80% of equipment failures are self induced; most of those are a result of human error. All human error failures can't be blamed on education or skills, but they do make the problem worse.

The U.S. Department of Education funded a survey by the Bureau of Census to determine how training impacts productivity. The survey revealed that increasing an individual's educational level by 10% increases the productivity by 8.6%. Several other research studies have indicated similar results. Educated and skilled workforce improves productivity and reduces human-induced errors.

A well-developed training program based on job task analysis and maintenance skills assessment can provide the solution to inadequate maintenance skills availability. The training must be focused to produce results as quickly as possible and must also meet an organization's long-term goals. Maintenance training, when developed and implemented properly, can help organizations save money, increase productivity and product quality, and improve employee morale.

The training curriculum should include the following but not limited to:

a) Regulatory and safety requirements, e.g. OSHA, EPA, FDA
b) Technical
    i) Asset /system — operation and maintenance
    To provide basic understanding of how an asset or system operates and how it interfaces with utilities and other assets. It may include minimum maintenance needs or operator-required maintenance.
    ii) Specific repair techniques and technology
    To provide new repair techniques or technology-related

training, e.g., hydraulic servo valves, vibration, ultrasonic, and laser alignment.

iii) Professional development
RCM, FMEA, 6-Sigma tools, blueprint reading, etc.

c) Organization specific, i.e. process related — how to write work orders or requests for material, company diversity policy, etc.

In addition, the organizations may provide remedial enhancement educational courses to improve basic reading and math capabilities. This could be done economically through local community colleges.

It is also a good practice to track employee training records by establishing a training data base. This data base should include:

- Training required with due date
- Training completed by date with hours credited
- Any mandatory, regulatory, or qualification training required, e.g., waste water operators, welding, special equipment oper ations or maintainer
- Skill assessment information
- Certifications achieved, etc.

Training Resources and Benchmark

How much money should we spend on training; how much is good enough? Many organizations face this dilemma. Some managers believe that money spent on training has a very low or poor return on investment. In reality, this is not so, because benefits and results can not be realized in the short term. Training metrics are lagging indicators and it takes a while to see the results. Figure 10.1 lists typical benchmark data, based on reviewing several benchmark studies and my personal discussion with many M&R and Training Managers.

Training Benchmark	Low	High	Best of the Best
Percentage of Overall Budget — Payroll	0.5	6.4	4.5
Expenditure per Employee in $	650	5,000	4200
Training Hours / Employee	5	110	96

Figure 10.1

In a recent survey of 984 North American manufacturing plants, the Manufacturing Performance Group (MPI) found:

Training Levels (more than 40 hours /year /person)

- United States 18%
- Canada 17%
- Mexico 29%

Only 18% of manufacturers in the United States are spending more than 40 hours per person annually on training, compared to 29% of Mexican manufacturers.

Certification and Qualification

Earlier in this chapter we discussed investing in our people to educate and train them. Organizations want their people to have a good understanding and appropriate skills in the M&R field in order to help them to become more efficient and effective. How do we know that they, the employees, have the required knowledge? How do we assess that knowledge? Did they comprehend the proper use of M&R tools and best practices during training sessions? Certification is a means to assess required knowledge or set of skills in a specific field.

Why do organizations need to get their people certified? What value does a certification provide? These are the questions raised by many organizations. One answer is "Can we afford not to get certified?" According to the U.S. Department of Labor, Bureau of Labor Statistics Outlook Handbook 2008/9 edition, "Many employers regard certifications as the industry standard." Certification measures and evaluates an employee's understanding of a body of knowledge in a specific area with a standard knowledge that has been established by an appropriate industrial or academic body. Most of the certifying organizations are either professional societies or educational institutions. Some of them have their certifying process comply with and approved by the American National Standard Institute (ANSI) and International Standards Organizations (ISO).

Certification in the M&R area, e.g., CMRP by SMRP, or Vibration Analyst X by Vibration Institute indicates that a successful applicant has the following attributes:

- Demonstrated knowledge in M&R field —
  concept and implementation
- Equipped with the skills to perform in specific area effectively

Employers of certified employees should be confident that they have individuals or new certified employees being hired who have proven themselves, possess the skill sets necessary for success, and have met a specific certification standard.

Certifications can be grouped in four major classifications:

1. Asset / System Level
2. M&R Technologies
3. Professionals / Managers
4. Plant /Facility Level

Asset / System Level

Assets and systems are getting much more complex. Many organizations have started to qualify operators and maintainers for critical and complex assets. Organizations need to assure that people who are going to operate and maintain have the appropriate skills. Operators and maintainers are required to go through a training curriculum specifically design to educate key aspects of that asset and then test their knowledge to ensure that they have comprehended the knowledge. Usually this type of certification or qualification requirements are developed and administered within the organizations. In some cases — where public assets are involved such as the operation of water treatment plants, boilers, etc. — such certification is provided by an outside agency.

M&R Technologies

Several CBM technology and general maintenance-related certifications are available such as oil analysis, machinery vibration analysis, infrared (IR) thermography, ultrasonic testing, motor current testing, hydraulics, and pressure vessels. These certifications are valuable to both employees and organizations. They test knowledge in related area of maintenance technologies. Training for most of these certifications is provided by the key suppliers of these technologies or related professional societies, who also administer the test.

M&R Professionals / Managers

In this category, maintenance and reliability engineers, capital project engineers, designers, managers, and other professionals working in the M&R field are tested for their broad knowledge of M&R.

Two key certifications are available in this category. One is Certified Plant Engineer (CPE) / Certified Maintenance Manager (CMM) offered by the Association of Facility Engineers (AFE). The other is

Certified Maintenance and Reliability Professional (CMRP) conducted by the Society of Maintenance and Reliability Professionals Certifying Organization (SMRPCO). AFE and some industrial training companies provide the necessary training for the CPE / CMM test.

The CMRP certification process is ANSI certified. According to ANSI requirements, SMRP/SMRPCO is prohibited from providing any specific training. However, SMRPCO has a study guide available in hard copy format from SMRP headquarters. This guide can be downloaded from their website www.smrp.org/certification free of cost.

CMRP certification was initiated in 2000 and is now recognized as the standard of M&R certification by many organizations worldwide. The certification process evaluates an individual's skills in the five pillars of knowledge defined by SMRP: Business and Management, Manufacturing/Operations Processes Reliability, Equipment Reliability, People Skills, and Work Management. Many organizations have now started using CMRP certification to assess their employees' knowledge and then to develop appropriate training programs that help their employees improve their skills.

Another certification available for reliability engineers, called Certified Reliability Engineers (CRE), is conducted by the American Society for Quality (ASQ). CRE deals with the quantitative and analytical skills employed by reliability engineers to manage reliability and risk. This certification is more technically inclined towards the product reliability professional.

Plant /Facility Level

There are no plant certifications available. However, two organizations recognize best plants/facilities. One is the North American Maintenance Excellence (NAME) Award given to a plant based on NAME-established criteria. The other is the "Best Plant" award conducted by the publishers of *Industry Week*. This award is not specific to M&R, but recognizes overall aspects of manufacturing plant operations, e.g., quality, productivity, meeting customer needs on a timely basis, and inventory levels.

10.5 Workforce Management

Developing people and managing them to be productive is a key factor in operating a successful business. The success of workforce management hinges on implementation of the following core, though interdependent goals.

a. Aligning the workforce with business strategy
b. Attracting, developing, and retaining key talent
c. Managing diversity
d. Designing organization structure for best integration of M&R functions
e. Succession planning
f. Developing a leadership culture
g. Establishing and maintaining a learning environment
h. Creating a flexible work environment

Aligning the Workforce with Business Strategy

Employees need to know why the organization is in business. Involve employees in creating or confirming the organization's mission. Crystallize the organization's reason for being and the direction it plans to take into the future. People support what they help to create.

Having the right people in the organization has a huge influence on successfully executing business strategy. Elevating workforce management to the level of a strategic function and aligning it with an organization's overall strategic direction can provide a focused approach to people development.

Attracting, Developing, and Retaining Key Talent

Individuals are still likely to shop around for better opportunities if they are not nurtured on the job. A well-defined process for developing people means enhancing career and succession planning programs to show employees that the organization is committed to their long-term success. It also means demonstrating a desire for strategic investment in career development programs. Five primary reasons why people leave or change jobs are listed below. A plan should be in place to minimize the impact of these factors.

1. **I don't fit in here.** This perspective is a corporate culture issue in most cases. Employees are also concerned with the organization's reputation; the physical conditions of comfort, convenience, safety, and the clarity of mission.
2. **They wouldn't miss me.** Even though managers do value employees, they don't tell them often enough. If people don't feel important, they're not motivated to stay. No one wants to be a commodity, easily replaced by someone off the street. They'll leave for a position where they're appreciated.
3. **I don't get the support to get my job done.** Most of the time,

people really do want to do a good job. When they're frustrated by too many rules, red tape, or incompetent supervisors or co-workers, employees look for other opportunities.

4. **Lack of opportunity for advancement.** People want to learn, to sharpen their skills, and to pick-up new ones. They want to improve their capacity to perform a wide variety of jobs. They desire better training opportunities and development. If people can't find the growth opportunities with one organization, they'll seek another employer where they can learn.
5. **Compensation is the last reason people leave.** Employees want fair compensation, but the first four aspects must be strong. If they're not, but compensation is high, you'll hear people say "you can't pay me enough to stay here."

Many organizations are either trying to lure valued retirees back to work or entice older workers to stay on the job longer. However, an organization needs to capture the knowledge that retiring baby boomers threaten to take with them. Mentoring is an effective way of transferring that knowledge. Assign young employees with experienced baby boomers and let them mentor and transfer their knowledge.

Today's workforce also likes to have stretch goals. It may require abandoning some old ways of doing things to optimize employees' options, and thus maximize chances of retaining nurtured talent. We need to make job opportunities visible across the organization, as well as invest in retraining and re-assignment of responsibilities. Of course, the right compensation plan is as crucial as career advancement opportunities for all high-performing employees.

Managing Diversity

Over 80% of the new entrants into the workforce today are women and minorities. This changing workforce is one of the major challenges facing businesses. Organizations that recognize the need to fully develop all members of the workforce are forced to manage diversity.

Definitions of "diversity" range from narrow to very broad. Narrow definitions tend to reflect Equal Employment Opportunity law, and define diversity in terms of race, gender, ethnicity, age, national origin, religion, and disability. Broad definitions may include sexual orientation, values, personality characteristics, education, language, physical appearance, marital status, lifestyle, beliefs, and background characteristics.

In the near future the labor market will become more and more of a seller's market. The shrinking workforce and the shortage of skilled labor will force employers to compete to attract and retain all available employees, including previously under-represented groups. These demographic changes have led many organizations to begin changing their cultures in order to value and manage diversity better.

According to 2004 U.S. Bureau of the Census projections (comparing 2020 to 2000), the percentage of workers aged 20–44 will decline from 36.9% to 32.3%; the number of workers aged 45–64 will increase from 22.1% to 24.9%; and the number of workers aged 65–84 will increase from 10.9% to 14.1%.

Such gray-haired demographics aren't limited to the United States either. The number of workers aged 20–44 will decrease and aged 45–84 increase in other countries such as the United Kingdom, Germany, Japan, and China.

Many boomers say they plan to balance work and leisure in retirement. They don't plan to stop working at age 65, instead opting for a "working retirement." The reasons are both financial and personal.

Several studies have found that many corporate policies hinder efforts to adapt to the aging workforce. Still, most organizations say they hire for ability and willingness to work. A few employers say they're "hiring wisdom" when hiring older workers. Gray-haired workers are viewed as reliable, settled, compassionate, and honest. Some organizations have set up a Casual Worker Program that allows them to hire or reemploy workers who would receive limited benefits and no pension.

Designing Organization Structure for Better Integration of M&R Functions

Throughout the industry, organizations are being flattened, intermediate layers of management are being removed, and the overall size of M&R departments are being reduced. This is the reality of today's competitive nature of the business.

In this environment, how organizations are structured to provide key M&R functions is important for effective use of its people. There are three types of organization structures which could be used to set up an M&R organization:

- Centralized
- De-centralized
- Hybrid

Any time we start discussing organization structure and skills, the first question that arises is which type of organization structure would be more beneficial: a centralized or decentralized structure (see Figure 10.2). Typically, a centralized organization structure is characterized by greater specialization and standardization. The decentralized structure provides stronger ownership and responsiveness.

Centralized		Decentralized	
Advantages	Disadvantages	Advantages	Disadvantages
Standardized practices	Less responsive to individual units / department	Strong ownership	Difficult to build specialized skills
Enterprise focus — objectives aligned with organization	Lack of ownership	Very responsive to individual area	Difficult to prioritize by facility/department
Efficient use of resources			Sub-optimum use of tools
Easy to build specialized skills			

Figure 10.2

Many experts have advocated shifting from one structure to another, centralized to decentralized, and vice versa. The primarily reason for this recommendation is not that one type is necessarily better than the other, but to bring about change. Shaking things up is necessary to break old, traditional practices. A hybrid structure, containing the best characteristics of both, centralized and decentralized, is sometimes the optimal solution.

In a hybrid organization, an individual production unit or area may have their own maintenance technician assigned to take care of area breakdowns and minor repairs. Operators become valuable resources as troubleshooting experts, or as system turnover or return-to-service technicians. In some cases, they provide extra hands in the repair process. The large PMs, major repairs, and specialized technical tasks such as PdM / CBM and critical alignments are performed by the centralized specialized staff.

In designing the organization structure, it is important to address the following M&R functions:

- PM program development
- Execution of PM and CM tasks
- Planning and scheduling
- Material — spares including tools availability
- CBM/ PdM and specialized skills, e.g., laser alignment

- Failure elimination and reliability planning
- Designing for reliability
- Resource management and budgeting
- Workforce development

A typical M&R organization structure is shown in Figure 10.3.

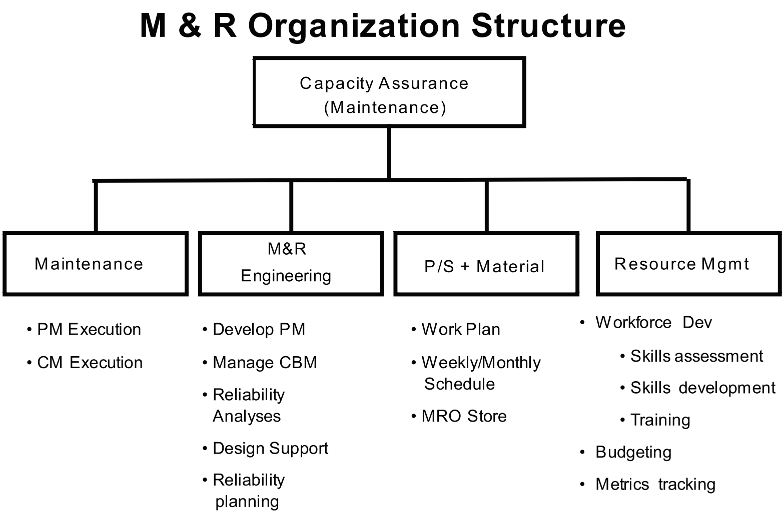


Figure 10.3 M & R Organization Structure

We are under increasing pressure to reduce our labor cost. If there are some constraints put on the number of employees we can have, under those circumstances we can evaluate outsourcing or shared services for some specific skills in order to obtain a cost-effective solution.

Succession Planning

Succession planning is another key element of the workforce development process. It is a process of identifying and preparing suitable employees — through mentoring, training, and job rotation — to replace key players in the organization. It involves having the management periodically review their key personnel and those in the next lower level to determine several backups for key positions. This is important because it often takes years of grooming to develop effective managers and leaders.

A careful and considered plan of action ensures the least possible disruption to the person's responsibilities and to the organization's effectiveness if suddenly a key player is not available to perform his or her role. Examples include:

- Sudden or unexpected inability or unwillingness to continue their role within the organization
- Acceptance of a position from another organization or external opportunity which will terminate or lessen their value to the current organization
- Conclusion of a contract or time-limited project
- Move to another position and different set of responsibilities within the organization.
- Plans to retire
- Serious illness or sudden death

The goal of succession planning is to continuously identify and develop high-performing leaders capable of meeting the future needs of the organization. Goals should include a formal identification process supported by leadership development that builds leadership capacity within the organization. Many organizations now use succession planning to address the succession of workers at many different levels as they leave the workforce. A workforce-planning strategy should include ongoing workforce training and leadership development to meet the looming challenge of an aging workforce.

Samuel Greengard, a noted management author, points out several key steps for successful succession planning in "Five Keys to Successful Succession Planning" in his book *Workforce Management*:

1. Identify key leadership criteria.
2. Find future leaders and motivate them.
3. Create a sense of responsibility within the organization.
4. Align succession planning with the corporate culture.
5. Measure results and reinforce desired behavior so that employees are prepared and trained for the jobs of tomorrow

Succession planning ensures that there are highly qualified people in all positions, not just today, but tomorrow, next year, and five years from now. Succession planning establishes a process that recruits employees, develops their skills and abilities, and prepares them for advancement, all while retaining them to guarantee a return on the organization's training investment. Succession planning involves the following steps:

- Determine critical positions.
- Identify current and future competencies for positions.
- Create assessment and selection tools.
- Identify gaps in current employee and candidate competency levels.
- Develop Individual development plans for employees.
- Develop and implement coaching and mentoring programs.
- Assist with leadership transition and development.
- Develop an evaluation plan for succession management.

Development of Leadership Culture

Managers and supervisors should be encouraged to become leaders. Directive, autocratic management style will soon become thing of the past. The leaders of tomorrow will need to be facilitative. Establishing agreed-upon results with individual performers, the managers will provide needed resources, support, and coaching. Part of the leader's role will be to help people reach their full potential, then raise the bar to keep them growing.

Leaders inspire, rather than direct. They coach, encourage, and guide. Effective leaders earn agreement with their people about what has to be done. They determine — with their team members — what resources are needed to get the job done. They arrange those resources and then get out of the way so their people can perform.

Leaders appreciate and recognize their people. People are hungry for appreciation. Thanking people every day, being sincere and specific, seeking creative ways to show that they are being cared are some of good leadership styles.

Leaders also endeavor to educate and train all managers to coach their team members on an ongoing basis. They focus on helping each worker learn how to improve performance. Continuous improvement is much more effective than annual appraisal alone. Supervisors / managers need to learn new coaching techniques to deal with a new diversified workforce.

Establish and Maintain Learning Environment

An environment conducive to learning is maintained by being supportive to personal and professional growth and by using education, training, and development to help every employee become more competent and confident. Personal and corporate growth objectives are linked to build an environment that bonds people to the organization. When people can meet their personal needs through their employment, they'll be more likely to stay.

"If you think training/education is expensive;
Try to count the cost of Ignorance."

Create a Flexible Work Environment

Rigidity in the employment environment is waning. Instead, the trend is toward more flexibility in work hours. Work styles such as working from home are being demanded. The organization's policies need to be reviewed and changes made if necessary to meet the needs of new workforce.

The move away from formality at work started with "casual Fridays" and now has moved to the acceptance of "corporate casual dress" every day. Relationships have become more informal. Research shows that the informality removes status barriers and improves measurable productivity

10.6 Summary

Big changes are happening in today's workforce. These changes have nothing to do with downsizing, global competition, or stress, it is the problem of a distinct generation gap. Young people entering the workforce are of diversified background and have much different attitudes about work. They want a life-work balance. They want to be led, not managed — and certainly not micro-managed. The new mode is flexibility and informality. A large proportion of our managers of the veteran era have been trained in relatively autocratic and directive methods that don't sit well with today's employees.

There's a very serious labor shortage right around the corner. According to data from the Bureau of Labor Statistics, there will be more jobs than people to fill them. In addition, people entering the workforce, specifically in the M&R field, lack basic skill sets as well as reading and math capabilities. There is a need to have people development programs in every organization to ensure a supply of skilled and talented workers.

The labor shortage will intensify. Finding qualified employees will be difficult. Workers will move easily from job to job in a flow we used to call "job hopping." The continual shifting will be commonplace.

Organizations will be caught unaware until they suddenly lose their best people. It is important to be prepared and have your program in place to retain them if possible, or to have back-up workers trained and ready to take new responsibility.

Organizations don't have to wait until they have an opening to recruit qualified applicants. They should have a list of screened potential employees, ready to call when we have the right opportunity for them. Internships, co-operative programs, and similar tools can be used to recruit and evaluate future employees. Succession planning for all positions and training of identified employees need to be developed. These steps will guarantee the availability of the right people when we need them. Succession planning is not just a simple replacement strategy. It involves forecasting workforce needs and developing ongoing strategies to meet those needs. Every person hired must meet minimum qualification standards. This practice sends a very clear message that we won't allow anyone who may drag us down. By adhering to this rule, organizations reinforce the high performance of current employees.

The organizational structure needs to be examined critically. Is the organization structured in an optimal way for smooth operation? Does it support productivity, accountability, and profitability? If not, changes have to be instituted to concentrate energies for results. People need to be cross-trained to enable them to work productively together across departmental or functional lines.

Despite all these efforts to attract, train, retain, and minimize the loss of critical skills and talent, the fact remains that we are under increasing pressure to adopt a more flexible workforce model in order to turn fixed cost into variable cost. Shared services and outsourcing need to be evaluated to obtain a cost-effective solution. Let us not forget that today's workforce — which consists primarily of Baby Boomers, Gen Xers, and Gen Yers with diversified, ethnic backgrounds — requires different sets of benefits and management style to keep them in the organization.

Finally, getting a workforce with the required knowledge and skill sets requires a long-term commitment. Aligning the workforce with overall business strategy is just a starting point. Organizations need to develop systematic approaches in attracting, developing, and retaining key young talent, while at the same time minimizing the loss of those critical skills that older workers possess in abundance. Additionally, only by continually challenging the people can we build a more flexible workforce model. It is people or, more aptly, the right people that make things happen

10.7 References and Suggested Reading

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Chapter 11

M & R Analysis Tools

Every problem is an opportunity.
—Kilchiro Toyoda, founder of Toyota

After reading the chapter, the reader will be able to understand:

- Why analysis tools are necessary?
- What analysis tools to use when and where?
- What's the difference between EAM and CMMS?
- Objective of CMMS/EAM

11.1 Introduction

Businesses must continually improve processes, reduce costs, and cut waste to remain competitive. Data (O&M data) need to be analyzed using various techniques and tools in order to develop and implement effective plans that can lead to improvements in assets and processes. A variety of techniques are available, ranging from simple check lists and spreadsheets to sophisticated modeling software that is helpful for developing appropriate improvement plans. In this chapter, we will discuss a few of these M&R tools in brief and describe situation in which they can appropriately be used. In addition, we will discuss Computerized Maintenance Management Systems, an essential tool to improve maintenance effectiveness.

Key terms related to M&R analysis tools are listed below:

Key Terms and Definitions

5 Whys

The 5 Whys is a simple problem-solving technique that helps users to get to the root of the problem quickly by simply asking why a number of times until the root cause become evident.

Barrier Analysis

A technique often used, particularly in process industries, based on tracing energy flows. It has a focus on barriers to those flows, and helps to identify how and why the barriers did not prevent the energy flows from causing damage.

Cause-and-Effects Analysis

Also called Ishikawa or fishbone chart. It identifies many possible causes for an effect or problem, then sorts ideas into useful categories to help in developing appropriate corrective actions.

Cause Mapping

A simple, but effective method of analyzing, documenting, communicating, and solving a problem to show how individual cause-and-effect relationships are inter-connected.

Checklists

A generic tool that can be developed for a wide variety of purposes. It is a structured, pre-prepared form for collecting, recording, and analyzing data as the work progresses. Some examples are operator's start-up checklist, PM checklist, and maintainability checklist used by designers.

Control Charts

A graph used to display how a process changes over time. Comparing current data to historical control limits indicates process variations whether the process is in control or out of control.

Design for Six Sigma (DFSS)

A systematic methodology using tools and training to enable the design of products, processes, and services that meet customer expectations at 6 Sigma quality levels. DFSS optimizes the design process to achieve a very high quality and repeatable 6 Sigma performances. It follows a five-phase process called DMADV (Define – Measure – Analyze – Design – Verify), which is sometimes synonymously referred to as DFSS.

Design of Experiments (DOE)

A method for carrying out carefully planned experiments on a process. Usually, design of experiments involves a series of experiments that start by looking broadly at a large numbers of variables and then focus on the few critical ones.

Failure Modes and Effects Analysis (FMEA)

Failure modes and effects analysis (FMEA) is a step-by-step approach for identifying all possible failures in a design, maintenance, manufacturing or assembly process, or service. "Failure modes" are the ways, or modes, in which something might fail. Failures are any errors or defects, especially those that affect the customer or process; can be potential or actual. "Effects analysis" refers to studying the consequences of those failures. Failures are prioritized according to how serious their consequences are, how frequently they occur, and how easily they can be detected. The purpose of the FMEA is to take actions to eliminate or reduce failures, starting with the highest-priority (failures with high serious consequences) ones.

Fault Tree

This analysis tool is constructed starting with the final failure (or event) and progressively tracing each cause that led to the previous cause. This continues till the trail can be traced back no further. Once the fault tree is completed and checked for logical flow, it is determined what changes would prevent the sequence of causes (or events) with marked consequences from occurring again.

Flow Chart

A flow chart is a picture of the separate steps of a process in sequential order. Elements that may be included are: sequence of actions, materials or services entering or leaving the process (inputs and outputs), decisions that must be made, people who become involved, time involved at each step, and process measurement parameters. The process described can be almost anything: a manufacturing process, maintenance planning process, or RCM process. This is a generic tool that can be adapted for a wide variety of purposes.

Histogram

The most commonly used graph for showing frequency distributions, or how often each different value in a set of data occurs.

Mistake Proofing

Mistake proofing, also known as Poka-Yoke (Japanese equivalent), is the use of any automatic device or method that either makes it impossible for an error to occur or makes the error immediately obvious once it has occurred.

Pareto Analysis

A Pareto chart is a bar graph. The lengths of the bars represent frequency (or cost) and are arranged with longest bars on the left and the shortest to the right. This arrangement illustrates which situations are more significant then others. The concept is also known as 80/20 Principle.

PDCA – Deming's Improvement Cycle

Plan – Do – Check – Act (PDCA) is known as Deming's methodology to make improvements.

Root Cause Analysis

Root Cause Analysis (RCA), sometime called Root Cause Failure Analysis (RCFA), is a step-by-step methodology that leads to the discovery of cause of the failure or root cause.

Scatter Diagram

A diagram that graphs pairs of numerical data, one variable on each axis, to look for a trend or a relationship

Six Sigma

This methodology systemically analyzes processes to reduce process variations and also to eliminate wastes. Six Sigma is also used to further drive productivity and quality improvements in lean operations. DMAIC (**D**efine – **M**easure – **A**nalyze – **I**mprove – **C**ontrol) represents the steps used to guide implementation of the Six Sigma process.

Standard Deviation

Standard deviation measures variations of values from the mean. It is denoted by Greek letter (σ) and is calculated using the following formula:

$$\sigma = \sqrt{\frac{\sum (x_i - \bar{x})^2}{(n-1)}}$$

where, Σ sum of, X_i = observed values, X bar (X with a line over the top) = arithmetic mean, and n = number of observations.

Stratification

A technique that separates data gathered from a variety of sources so that a pattern can be seen.

Theory of Constraints (TOC)

This theory is based on the fact that, like a chain with its weakest link, any system or process has at any point in time one aspect that is limiting (or constraining) its ability to achieve most of its goal. For that system to attain any significant improvement, that constraint must be identified and the whole system must be managed with this limitation in mind. Thus, to increase throughput, we must identify and eliminate the constraint (or bottleneck). TOC is also sometime referred as Bottleneck analysis.

Value Stream Mapping (VSM)

VSM is a tool that helps to visualize and understand the flow of information and material as it makes its way through the process value stream. It identifies steps which are not adding any value — they are waste and needed to be removed from the process or improved.

11.2 Analysis Tools

5 Whys Analysis

The 5 Whys is a simple problem-solving technique that helps users get to the root of the problem quickly. Made popular in the 1970s by the Toyota Production System, the 5 Whys strategy involves looking at any problem and asking: "Why?" and "What caused this problem? Very often, the answer to the first *why* will prompt another *why* and the answer to the second *why* will prompt another, and so on — hence the name the 5 Whys strategy.

Benefits of the 5 Whys include:

- It helps to quickly determine the root cause of a problem.
- It is easy to learn and apply.

How to Use the Tool

When looking to solve a problem, start at the end result and work backward (toward the root cause), continually asking, "Why?" This process will need to be repeated over and over until the root cause of the problem becomes apparent. If it doesn't quickly give an answer that's obviously right, then you may need more sophisticated problem-solving technique.

Example

The following example shows the effectiveness of the 5 Whys analysis as a problem-solving technique:

1. Why is our customer (operations department **xyz**) unhappy?
    - Because we did not deliver our services (fixing the asset) when we said we would.
2. Why were we unable to meet the agreed-upon schedule for delivery?
    - The job took much longer than we thought it would.
3. Why did it take so much longer?
    - Because we underestimated the work requirements.
4. Why did we underestimate the work?
    - Because we made a quick estimate of the time needed to complete it, and did not list the individual steps need ed to complete the total job. In short, we did not do work planning for this job.
5. Why didn't we do planning — detailed analysis — for this job?

- Because we were running behind on other projects and were short on planner's resources. Our customer (operations department xyz) was forcing us to do the job quickly. Clearly, we needed better planning, including improved time estimations and steps needed to complete the job efficiently.

The 5 Whys strategy is an easy and often effective tool for uncovering the root causes of a problem. Because it is so elementary in nature, it can be adapted quickly and applied to almost any problem. Remember, if it doesn't prompt an intuitive answer, other problem-solving techniques may need to be applied.

Cause-and-Effects Analysis (or Fishbone Diagram)

What Is a Fishbone Diagram?

Dr. Kaoru Ishikawa, a Japanese quality control statistician, invented the fishbone diagram, which often looks like the skeleton of a fish, hence its name. The fishbone diagram is an analytical tool that provides a systematic way of looking at effects and the causes that create or contribute to those effects. Because of this function of the fishbone diagram, it is also called a Cause-and-Effect Diagram.

Whatever name we choose to call this analysis, it helps us in a systematic and simply way to categorize the many potential causes of problems and to identify root causes. Usually this analysis is performed as a team. After listing the possible causes for a problem, the team can analyze each cause carefully, giving due importance to statements made by each team member during the brainstorming session, accepting or ruling out certain causes, and eventually arriving at the root cause of the problem. In general, fishbone diagrams give us increased understanding of complex problems by visual means of analyses.

When Should We Use a Fishbone Diagram?

It is helpful to use the fishbone diagram in the following cases:

- To stimulate thinking during a brain-storming session
- When there are many possible causes for a problem
- To evaluate all the possible reasons when a process is beginning to have difficulties, problems, or breakdowns?
- To investigate why an asset or process is not performing properly or producing the desired results?

- To analyze and find the root causes of a complicated problem and to understand relationships between potential causes
- To dissect problems into smaller pieces

When Should We Not Use a Fishbone Diagram?

Of course, the Fishbone diagram isn't applicable to every situation. Listed below are just a few examples in which we should not use the Fishbone diagram because the diagram either is not relevant or does not produce the expected results:

- The problem is simple or is already known.
- The team size is too small for brainstorming.
- There is a communication problem among the team members.
- The team has experts who can fix any problem without much difficulty.

How to Construct a Fishbone Diagram

The following five steps are essential when constructing a fishbone diagram:

1. Define the problem.
2. Brainstorm.
3. Identify all causes.
4. Select any causes that may be at the root of the problem.
5. Develop corrective action plan to eliminate or reduce the impact of the causes selected in Step 4.

The first step is fairly simple and straightforward. Define the problem for which the root cause needs to be identified. Usually the maintenance / reliability engineer or technical leader chooses the problem that needs a permanent fix, and that is worth brainstorming with the team.

After the problem is identified, the team leader can start constructing the Fishbone diagram. The leader defines the problem in a square box to the right side of a page or worksheet. A straight line is drawn from the left to the problem box with an arrow pointing towards the box. The problem box now becomes the fish head and its bones are to be filled in during the steps that follow. Figure 11.1 provides an example of a Hydraulic Pump analysis. In this example, a hydraulic pump that is not pumping the desired output (oil) has become a problem.

The next step is to start identifying major components and suspected causes of this failure, e.g., bearing failure, motor failure, seal failure, or shaft failure. All major causes are identified and connected as parts

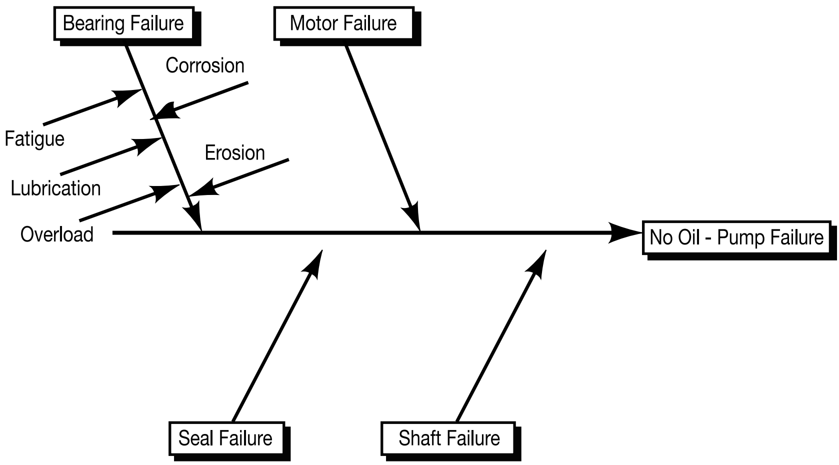

Figure 11.1 Fishbone Diagram: Failure of a Hydraulic Pump

of (the bones) the Fishbone diagram. Causes of bearing failures are also listed in this example. The next step is to refine the major causes to find the secondary causes and other causes occurring under each of the major categories.

In general, the following steps are taken to draw the fishbone diagram:

1. List the problem/issue to be investigated in the "head of the fish".
2. Label each "bone" of the "fish". Major categories typically include:
   - The 4 M's:
     - Methods, Machines, Materials, and Manpower
   - The 4 P's:
     - Place, Procedure, People, and Policies
   - The 4 S's:
     - Surroundings, Suppliers, Systems, and Skills
   - The 6 M's
     - Machine, Method, Materials, Measurement, Man, and Mother Nature (Environment)
   - The 6 EPM's
     - Equipment/Asset, Process, People, Materials, Environment, and Management.

3. The team may use one of the categories suggested above, combine them in any manner, or make up others as needed. The categories are to help organize the ideas.
4. Use an idea-generating technique (e.g., brainstorming) to identify the factors within each category that may be affecting the problem or effect being studied. The team should ask, "What is the issue and its cause and effect?"
5. Repeat this procedure with each factor under the category to produce sub-factors. Continue asking, "Why is this happening?" and put additional segments under each factor and subsequently under each sub-factor.
6. Continue until you no longer get useful information when you ask, "Why is that happening?"
7. Analyze the results of the fishbone after team members agree that an adequate amount of detail has been provided under each major category. For example, look for those items that appear in more than one category. These become the most likely causes.
8. For those items identified as the most likely causes, the team should reach consensus on their priority. The first item should be listed the most probable cause.

An example of another fishbone diagram is shown in Figure 11.2. In this example, an analysis team is trying to understand poor humidity control problem in a Drier application. The team used five specific headings to prompt the ideas.

Figure 11.3 shows yet another example of a fishbone diagram. Here, "Maintenance Excellence" is the problem statement (result). The diagram lists causes — in this case actions needed to be taken in order to achieve excellence in maintenance.

Sometimes the fishbone diagram can become very large because the team may identify many possible causes. This makes the diagram very complex; comprehending the relationship of the causes can be difficult. A good fishbone diagram is one which has explored all the possibilities for a problem, but is still easy to understand when developing corrective action plans.

Failure Modes and Effects Analysis (FMEA)

This analysis tool is also called failure modes, effects and criticality analysis (FMECA), and potential failure modes and effects analysis. (FMEA) is a step-by-step methodology for identifying all possible failures during the design of an asset (product) — in a manufacturing or assembly

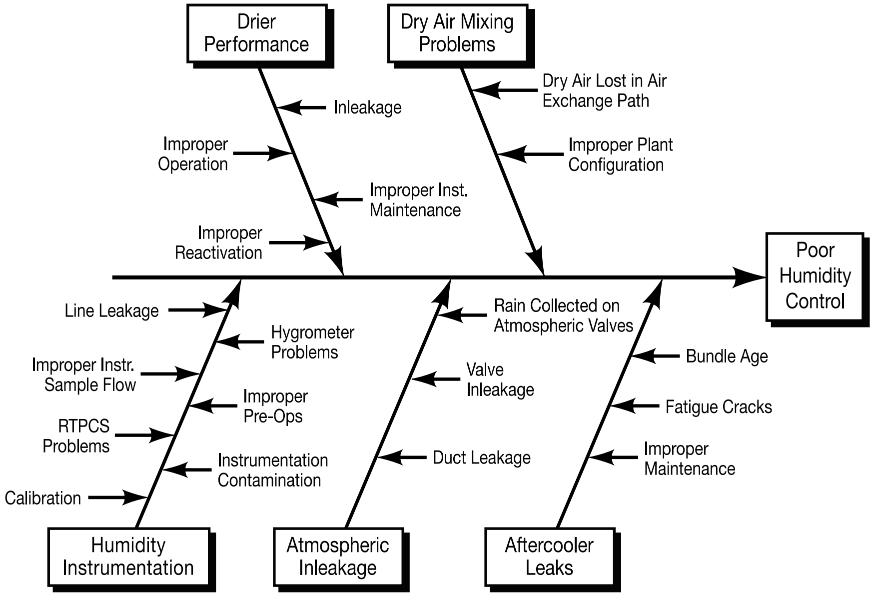

Figure 11.2 Fishbone Diagram: Poor Humidity Control Problem in Drier

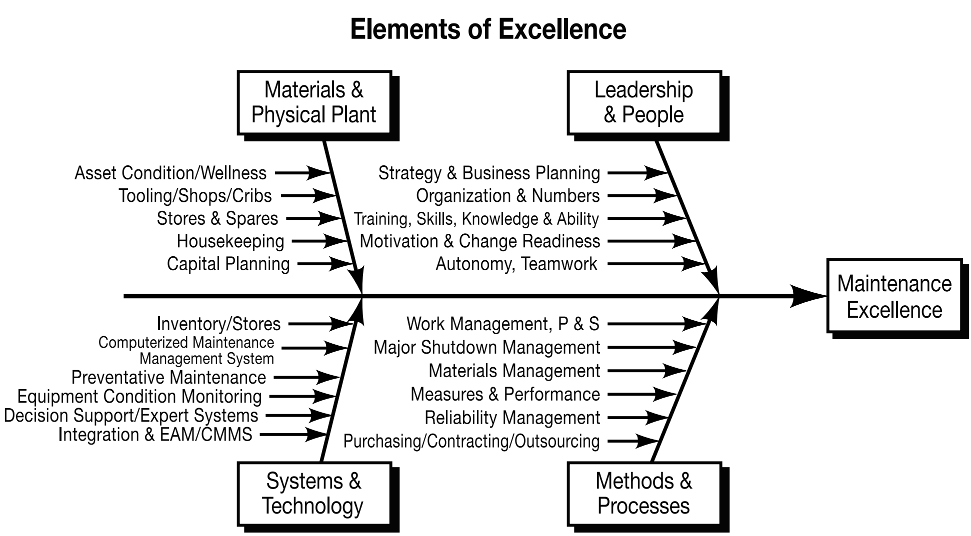

Figure 11.3 Elements of Excellence

process, in the operations and maintenance phase, or in providing services.

Failure modes means the ways, or modes, in which something might fail. Failures are any potential or actual errors or defects that affect the customer, user, or asset itself. Effects analysis refers to studying the consequences of those failures.

Failures are prioritized according to how serious their consequences are, how frequently they occur, and how easily they can be detected. The purpose of FMEA is to take actions to eliminate or reduce failures, starting with the highest-priority ones.

FMEA is an economical and effective tool for finding potential failures early in the design–development phase where it is easier to take actions to overcome these issues, thereby enhancing reliability through design. FMEA is used to identify potential failure modes and their effect on the operation of the assets; it also is helpful when developing effective PM actions to mitigate consequences of failure. It is an important step in anticipating what might go wrong with assets. Although anticipating every failure mode may not possible, the analysis team should formulate as extensive a list of potential failure modes as possible. Early and consistent use of FMEAs in the design process allows us to design out failures, in turn making assets more reliable and safe.

It has been observed that designers and engineers often use safety factor as a way of making sure that the design will work and protect the asset (product) and user upon failure. In the past, asset and systems designers have not done a good job designing in reliability and quality into the asset. The use of a large safety factor does not necessarily translate into a reliable asset. In fact, it often leads to an overdesigned product with reliability problems.

Types and Usage of FMEAs

There are several types of FMEAs, based on how and where it is used, e.g., in the design–development, operations, or maintenance phase of the assets. FMEAs should always be performed whenever failures could create potential harm or injury to the user (operator), environmental challenges, or break down of the asset, in turn causing loss of production. FMEAs can be classified in the following categories:

- Design: focuses on components and subsystems
- Process: focuses on manufacturing and assembly processes
- Maintenance: focuses on asset functions
- Service: focuses on service functions
- Software: focuses on software functions

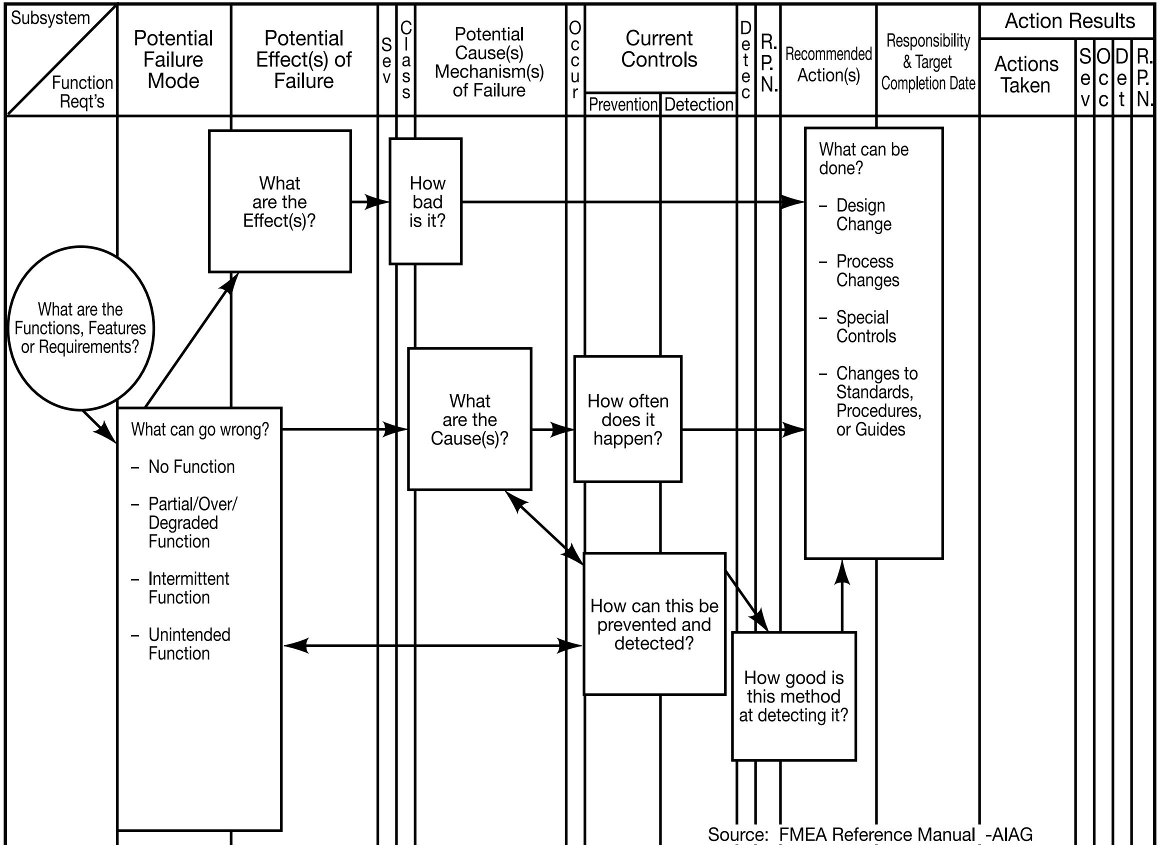

Figure 11.4
FMEA Steps

Although the purpose, terminology, and other details can vary according to type (e.g., Process FMEA, Design FMEA), the basic methodology is similar for all.

Figure 11.4 depicts the sequence in which a FMEA is performed. The typical sequence of steps answers the following set of questions:

1. What are the components and the functions they provide?
2. What can go wrong?
3. What are the effects?
4. How bad are the effects?
5. What are the causes?
6. How often can they fail?
7. How can this be prevented?
8. Can this be detected?
9. What can be done; what design, process, or procedural changes can be made?

Published Standards and Guidelines

There are a number of published guidelines and standards for the requirements and recommended reporting format of FMEAs. Some of the key published standards for this analysis include

- SAE J1739,
- AIAG FMEA-3
- MIL-STD-1629A (out of print / cancelled)

Automotive Industry Action Group (AIAG) guidelines and reference manual are very similar to SAE standard – J1739. Figure 11.5 shows the SAE/AIAG recommended format for performing and reporting FMEA

In addition, many industries and organizations have developed their own FMEA procedures and formats to meet the specific requirements of their products and processes. Figure 11.6 illustrates another organization's approach to documenting FMEA using a simple spreadsheet. Part a shows elements of Failure Modes Identification and Effects whereas Part b shows Prevention Impact and Mitigation Assessment.

In general, FMEA requires the identification of the following basic information:

- Items — components
- Functions
- Failure modes

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POTENTIAL
FAILURE MODE AND EFFECTS ANALYSIS
Front Door L.H.

System: 1 - Automobile
Subsystem: 2 - Closure
X Component: 3 - Front Door L.H.
Model Year(s)/Vehicles(s): 199X/Lion4dr/Wagon
Core Team: A. Tate Body Engrg, J. Smith - Oc, R. James - Production, J. Jones - Maintenance

Process Responsibility: Body Engineering
Key Date: 3/31/2003

FMEA Number: 1450
Page 1 of 1
Prepared By: J. Ford - X5621 - Assy Ops
FMEA Date (Orig.): 3/10/2003 (Rev): 3/21/2003

Item / Process Function/ Requirements	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Class	Potential Cause(s)/ Mechanism(s) of Failure	Occur	Current Process Controls Prevention	Current Process Controls Detection	Detec	RPN	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken: Actions Taken	Actions Taken: Sec	Actions Taken: Occ	Actions Taken: Det	Actions Taken: RPN
Manual application of wax inside door. To cover inner door, lowersurfaces at minimum wax thickness to retard corrosion.	Insufficient wax coverage over-specified surface.	Deteriorated life of door leading to: - Unsatisfactory appearance due to rust through paint overtime. - Impaired function of interior door hardware.	7		Manually inserted spray head not in inserted for enough.	8		Visual check each hour -1/ shift for film thickness (depth meter) and coverage.	6	280	Add positive depth stop to sprayer.		Stop added, sprayer checked on line.	7	2	5	70
					Spray head clogged - Viscosity too high - Temperature too low - Pressure too low.	5		Test spray pattern at start-up and after idle periods, and preventive maintenance program to clean heads.	5	105				7	1	3	21
					Spray head deformed due to impact.	2		Preventive maintenance program to maintain heads.	2	28				7	2	2	28
					Spray time insufficient.	8		Operator instructions and lot sampling (10 doors/ shift) to check for coverage of critical areas.	7	392				7	1	7	49

Figure 11.5
SAE/AIAG Guidelines

Chapter 12

Current Trends and Practices

12.1 Arc Flash Hazards and Prevention

Introduction

Bureau of Labor Statistics data reveal that between 1992 and 2002, electrical accidents in the workplace caused 3,378 deaths and an additional 46,598 non-fatal injuries. About 5% of all workplace deaths were related to electrical equipment. These statistics were validated in a second study involving more than 120,000 employees; this study determined that arc flash injuries accounted for the largest category of all recorded electrical injuries. Arc flash is responsible for a significant fraction of total electrical deaths and injuries.

As defined by IEEE and the National Fire Protection Association (NFPA), arc flash is a strong electric current — and sometimes a full-blown explosion — that passes through air when insulation between energized conductors or between an energized conductor and ground is no longer sufficient to contain the voltage between them. This creates a "short cut" that allows electricity to race from conductor-to-conductor, to the extreme detriment of any worker standing nearby. Arc flash resembles a lightning bolt-like charge, emitting heat to reach temperatures of 35,000 ^{O}F, which is hotter than the surface temperature of the sun, in 1/1000 of a second. Anyone exposed to the blast or heat without sufficient personal protective equipment (PPE) would be severely, and oftentimes fatally, injured.

An arc flash can cause substantial damage, fire, or injury. The massive energy released in the fault instantly vaporizes the metal conductors involved, blasting molten metal and expanding plasma outward with extreme force. The result of the violent event can cause destruction of the equipment involved, fire, and injury not only to the worker, but also to people and equipment nearby.

Usually a fire produces roughly 50% convective heat (flame) and 50% radiant heat. An arc can be up to 90% radiant heat. This level can produce severe burns when there is little or no flame present. In addition to the explosive blast of such a fault, destruction also arises from the intense radiant heat produced by the arc. The metal plasma arc produces tremendous amounts of light energy from far infrared to ultraviolet. Surfaces of nearby people and objects absorb this energy and are instantly heated to vaporizing temperatures. The effects of this can be seen on adjacent walls and equipment, which are often ablated and eroded from the radiant effects.

An arc flash can occur when a conductive object gets too close to an exposed current source. Dropping tools, opening equipment doors, racking breakers, and even checking voltage can cause an arc flash unless proper safety precautions are taken. Warning labels that inform workers of potential hazards are a key part of arc flash protection.

Causes and Damage by Arc Flash

Arcs can be initiated by a variety of causes, such as when:

- Workers incorrectly think the equipment is de-energized and begin to work on it energized.
- Workers drop or improperly use tools or components on an energized system.
- Dust, water, or other contamination accumulate and cause insulation breakdown.
- Connections loosen, overheat, and reach thermal runaway and fail.

Exposure to an arc flash frequently results in a variety of serious injuries and, in some cases, death. Workers have been injured even though they were ten feet or more away from the arc center. Worker injuries can include damaged hearing, eyesight, and severe burns requiring years of skin grafting and rehabilitation.

The pressure waves can also propel loose material like molten metal, pieces of damaged equipment, tools and other objects, through the air.

A hazardous arc flash can occur in any electrical device, regardless of voltage, in which the energy is high enough to sustain an arc. Potential places where this can happen include:

- Panel boards and switchboards
- Motor control centers
- Metal clad switch gear
- Transformers
- Motor starters and drive cabinets
- Fused disconnects
- Any place that can have an electrical equipment failure

Some of the employees at risk from arc flash hazards include mechanics, electricians, and HVAC personnel. The most dangerous tasks include:

- Removing or installing circuit breakers or fuses
- Working on control circuits with energized parts exposed
- Opening or closing circuit breakers or disconnects
- Applying safety grounds
- Removing panel covers

Standards and Labeling

Five separate industry standards been established for the prevention of arc flash incidents in the North America:

1. OSHA Standards 29-CFR, Part 1910. *Occupational Safety and Health Standards*. 1910 sub part S (electrical) Standard number 1910.333 specifically addresses Standards for Work Practices and references NFPA 70E.
2. The National Fire Protection Association (NFPA) Standard 70 2008 *The National Electrical Code* (NEC) contains requirements for warning labels.
3. NFPA 70E 2009 *Standard for Electrical Safety in the Workplace* provides guidance on implementing appropriate work practices that are required to safeguard workers from injury while working on or near exposed electrical conductors or circuit parts that could become energized.
4. The Canadian Standards Association's CSA Z462 *Arc Flash Standard*. It is Canada's version of NFPA 70E
5. The Institute of Electronics and Electrical Engineers IEEE 1584a 2004, *IEEE Guide to Performing Arc-Flash Hazard Calculations*.

Several arc flash hazard software programs are available commercially that allow organizations to comply with the myriad of government regulations while providing their workforce with an optimally safe environment.

Because of the dangers of electrical explosions, OSHA now legally requires employers to follow the NFPA recommended practices to protect workers from arc flash exposure. OSHA's 1910.132(d) and 1926.28(a) state that the employer is responsible to assess the hazards in the work place; select, have, and use the correct PPE; and document the assessment. Although OSHA does not, per se, enforce the NFPA 70E standard, OSHA considers the NFPA standard a recognized industry practice. Electrical inspectors also are now enforcing the new labeling requirements set forth in the 2008 National Electric Code (NEC).

Compliance with OSHA involves adherence to a six-point plan:

1. A facility must provide, and be able to demonstrate, a safety program with defined responsibilities.
2. Establish shock and flash protection boundaries.
3. Provide protective clothing (PC) and personal protective equipment (PPE) that meet ANSI standards.
4. Training for workers on the hazards of arc flash.
5. Appropriate tools for safe working.
6. Warning labels on equipment. Note that the labels are provided by the equipment owners, not the manufacturers. 110.16 NFPA 70E 2009 requires labels with the available incident energy or required level of PPE.

Personal Protection Equipment (PPE)

PPE is used to limit the injury incurred during a fault to a level no greater than the exposure of bare skin to an open flame for approximately 1 second (approx 1.2 cal/cm^2, a curable 2nd degree burn). If an Arc Flash study has not been performed, NFPA 70E tables can help to determine correct PPE. In some cases, the PPE worn by qualified personnel is oversized for a certain task in a specific location. In other cases where improper equipment is installed or existing equipment is maintained improperly, the Arc Flash energy could be much greater than what their PPE can protect them from. If a fault has Arc Flash energy greater than 40 cal/cm^2, the pressure wave will be so great that PPE can no longer provide adequate protection. Arc Flash analysis can help in determining on how to reduce Arc Flash energy to safer levels.

With recent increased awareness of the dangers of Arc Flash, there have been many companies that offer Arc Flash PPE. The fabrics or materials are tested for their Arc Rating. The Arc Rating is the maximum incident energy resistance demonstrated by a material prior to breakopen or at the onset of a second-degree skin burn. Arc Rating is normally expressed in cal/cm^2 (or calories of heat energy per square centimeter). The tests for determining Arc Rating is defined in ASTM 2002a *Standard Performance Specification for Flame Resistant Textile Materials for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards.*

Selection of appropriate PPE, given a certain task to be performed, is normally handled by one of two possible ways. The first method is to consult a Hazard category Classification table, like that found in NFPA 70E. Table 130.7(C)(9) lists a number of typical electrical tasks and their various voltage levels and Table 130.7(C)(10) recommends PPE that should be worn. For example, when working on 600V switchgear and performing a removal of bolted covers to expose bare, energized parts, the table recommends Category 4 Protective Clothing System. This Category 4 system corresponds to an ensemble of PPE that together offers protection up to 40 cal/cm^2. The minimum rating of PPE necessary for any Category is the maximum available energy for that Category. For example, a Category 3 arc-flash hazard requires PPE rated for no less than 25 cal/cm^2.

The second method of selecting PPE is to perform an Arc Flash hazard calculation to determine the available incident arc energy. Both, IEEE 1584a and NFPA 70E standards provide guidance to perform these calculations, given the bolted fault current, duration of faults, and other general equipment information are known. Once the incident energy is calculated, the appropriate ensemble of PPE that offers protection greater than the energy available can be selected.

PPE provides protection after an arc flash incident has occurred and should be viewed as the last line of protection. Reducing the frequency and severity of incidents should be the first option. This reduction can be achieved through a complete arc flash hazard assessment and through the application of technology such as High Resistance Grounding which has been proven to reduce the frequency and severity of incidents.

The flash protection boundary is based on voltage, available short-circuit current, and predicted fault duration. The NFPA 70E provides four acceptable methods of determining flash protection boundary:

- Analysis based on IEEE 1584
- Analysis based on NFPA 70E 130.3(A) and Annex D
- Simplified Two-Category FR Clothing System, Annex H
- The hazard risk categories provided by Table 130.7(C)(9)(a)

All of the known methods have some limitations. The tables provided by NFPA may be easy to use, but they are based on typical equipment and systems and are only approximations. They also require information from an up-to-date short circuit and coordination study. Detailed analysis yields different results than the tables do. Therefore, whatever method we use, it is necessary to understand its limitations. Years of industry application experience have resulted in the IEEE1584 standard referenced in NFPA 70E as being the preferred method for a comprehensive arc flash analysis

The NFPA 70E method estimates incident energy based on a theoretical maximum value of power dissipated by arcing faults. This is believed to be generally conservative. In contrast, IEEE 1584 estimates incident energy with empirical equations developed from statistical analysis of measurements taken from numerous laboratory tests.

Categories of PPE as described in NFPA 70E are shown in Figure 12.1.

Category	Cal/cm^2	Typical Clothing
0	1.2	Untreated Cotton
1	4	Flame retardant (FR) shirt and pants
2	8	Cotton underwear, FR shirts and pants
3	25	Cotton underwear, FR shirts and pants, and FR coveralls
4	40	Cotton underwear, FR shirts and pants, and double layer switching coat and pants

Figure 12.1 Categories of PPE for Arc Flash.

Cal/cm.^{2} is the unit of incident energy that the PPE can withstand. Note that a hard hat with full-face shield, hearing protection and the appropriate gloves may be also required.

Figure 12.2
A Full Category 4 Suit.

Figure 12.2 shows a person in a full Category 4 suit. This suit will provide the necessary protection, but it is cumbersome to work in, it is hot, and it provides poor visibility. The suits will make many tasks very difficult, if not impossible, to perform. Because of their restrictions to vision and movement, they may even make some tasks more dangerous. There are definitely times when this type of protection is both necessary and required, but being overly conservative will result in excessive stress to workers and unacceptable time to make repairs or adjustments.

Safety and Prevention

Preventive maintenance, worker training, and an effective safety program can significantly reduce arc flash exposure. Preventive maintenance should be conducted on a routine basis to ensure safe operation. As part of a preventive maintenance program, equipment should be thoroughly cleaned and routine inspections should be conducted by qualified personnel who understand how to uncover loose connections, overheated terminals, discoloration of nearby insulation, and pitted contacts. A comprehensive preventive maintenance plan should also include:

- Using corrosion-resistant terminals and insulating exposed metal parts, if possible
- Sealing all open areas of equipment to ensure rodents and birds cannot enter
- Verifying that all relays and breakers are set and operate properly

In order to select the proper PPE, incident energy must be known at every point where workers may be required to perform work on energized equipment. These calculations need to be performed by a qualified person such as an electrical engineer. All parts of the body that may be exposed to the arc flash need to be covered by the appropriate type and quality of PPE.

Reducing Hazard by Design

Three key factors determine the intensity of an Arc Flash event on personnel. These factors are the quantity of fault current available in a system, the fault until an arc flash is cleared, and the distance an individual is from an arc. Various design and equipment configuration choices can be made to affect these factors and, in turn, reduce the Arc Flash hazard.

Fault current can be limited by using current limiting devices such as grounding resistors or fuses. If the fault current is limited to 5 amps or less, then many ground faults self-extinguish and do not propagate into phase-to-phase faults.

Arcing time can be reduced by temporarily setting upstream protective devices to lower set points during maintenance periods or by employing zone interlocking (ZSIP).

Remote operators or robots can be used to perform activities that are high risk for Arc Flash incidents like racking breakers on a live electrical bus. The distance from an arc flash source within which an unprotected person has a 0% chance of receiving a second degree burn is referred to as the "flash protection boundary". Those conducting flash hazard analyses must determine this boundary, and then must determine what PPE should be worn within the flash protection boundary.

12.2 Communication and Problem Solving Skills

Introduction — Why Communication Is Important?

People in organizations typically spend over 75% of their time in an interpersonal situation to get work done. It is no surprise to find that poor communications are at the root of a large number of organizational problems. Effective communication is an essential component of organizational success whether it is at the interpersonal, intergroup, intra-group, organizational, or external level.

Effective communication is all about conveying messages to other people clearly and unambiguously. It's also about receiving information that others send to us, with as little distortion as possible.

Expressing our feelings, thoughts, and opinions clearly and effectively is only half of the communication process needed for interpersonal effectiveness. The other half is listening and understanding what others communicate to us. When we decide to communicate with another person, we do it to fulfill a need. In deciding to communicate, we select the method or code which we believe will effectively deliver the message to the other person. The code used to send the message can be either verbal or nonverbal. When the other person receives the coded message, they go through the process of decoding or interpreting it into understanding and meaning.

Effective communication exists between two people when the receiver interprets and understands the sender's message in the same way the sender intended it. By successfully getting the message across, we convey our thoughts and ideas effectively. When not successful, the thoughts and ideas that we actually send do not necessarily reflect what we think, causing a communications breakdown and creating roadblocks that stand in the way of our and the organization's success — both personally and professionally.

Communication Process

Problems with communication can be at every stage of the communication process (see Figure 12.3):

- Sender (source)
- Encoding
- Channel – media
- Decoding
- Receiver
- Feedback

At each stage, there is the potential for misunderstanding and confusion.

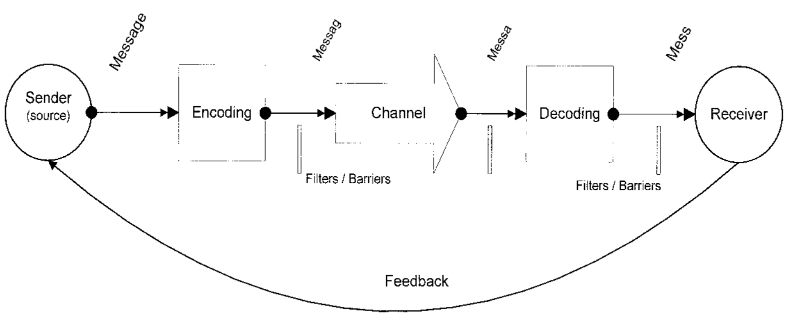

Figure 12.3 Communication Process.

To be an effective communicator and to get our point across without misunderstanding and confusion, our goal should be to reduce the frequency of problems at each stage of this process, with clear, concise, accurate, well-planned communications. The communication process is shown in Fig. 12.3. The key elements of this process are:

- **Sender.** The sender, who is the source of the message, needs to be clear about why we're communicating, and what we want to communicate. In addition, the sender needs to ensure that the information being communicated is useful and accurate.
- **Message.** The message is the information that we want to communicate.

- **Encoding.** This is the process of transferring the information we want to communicate into a form that can be sent and correctly decoded at the other end. Success in encoding depends partly on our ability to convey information clearly and simply, but also to anticipate and eliminate sources of confusion. For example, cultural issues, wrong assumptions, and missing information can interfere with clear communication. Failure to understand who we are communicating with will result in delivering messages that are misunderstood.
- **Channel.** We convey our message through the channel or media. Channels can be verbal, including face-to-face meetings, telephone, and videoconferencing. Written channels include letters, emails, memos, and reports.
- **Decoding.** In order to understand the message correctly, we must decode it, which involves taking time to read the message carefully or listening actively. Just as confusion can arise from errors in encoding, it can also arise from decoding errors. This is particularly the case if the decoder doesn't have enough knowledge to understand the message. Listening is a very important skill which will be discussed in more detail.
- **Receiver.** The receiver is the person for whom the message was intended. Caution: To be a successful communicator, we should consider how the receiver will react to the message.
- **Feedback.** Feedback is what the receiver sends back to us as ver bal and nonverbal reactions to our communicated message. We need to pay close attention to this feedback, as it is the only thing that can give us assurance the audience has understood our message. If we find that there has been a misunderstanding, at least now we have the opportunity to send the message a second time to clarify the issue.

Part of the feedback process involves understanding and predicting how the other person will react. We need to understand ways that we respond to feedback, especially threatening feedback.

Feedback provides basic need to improve, and to be accurate. It can be reinforcing; if given properly. It is crucial that we realize how critical feedback can be; it should be always appreciated.

Importance of Listening

"We were given two ears but only one mouth, because listening is

twice as hard as talking." Listening is one of the most important skills we can have. How well we listen has a major impact on our job effectiveness, and on the quality of our relationships with others. We listen to:

- Obtain information
- Understand
- Enjoy
- Learn

There are three basic listening modes:

1. **Competitive Listening.**
   This happens when we are more interested in promoting our own point of view than in understanding or exploring someone else's view. We either listen for openings to take the floor, or for flaws or weak points we can attack. We don't pay any attention to the "sender," but instead are formulating our rebuttal plan.
2. **Passive or Attentive Listening.**
   In this mode, we are genuinely interested in hearing and understanding the other person's point of view. We are attentive and passively listen.
3. **Active Listening.**
   In active listening, we are genuinely interested in understanding what the other person is thinking, feeling, or wanting, and what the message means. We actively check out our understanding before we respond with our own new message. Listening is a skill that we can all benefit from improving. By becoming better listeners, we will improve our productivity, as well as our ability to influence, persuade, and negotiate. What's more, we'll avoid conflict and misunderstandings — all necessary for workplace success.

Becoming an Active Listener

There are five elements of active listening. They all help us ensure that we hear the other person, and that the other person knows we are hearing what they are saying.

1. Pay attention.

Give the speaker undivided attention and acknowledge the message.

- Look at the speaker directly.
- Put aside distracting thoughts.
- "Listen" to the speaker's body language.
- Refrain from side conversations and avoid being distracted by environmental factors.

2. Show that we listening.

Use body language and gestures to convey that we are listening.

- Nod occasionally.
- Smile and use other facial expressions.
- Encourage the speaker to continue with small verbal comments like "yes" and "uh huh."

3. Provide feedback.

Our personal filters, assumptions, judgments, and beliefs can distort what we hear. As a listener, our role is to understand what is being said. This may require us to reflect what is being said and ask questions.

- Reflect what has been said by paraphrasing. "What I'm hearing is…" and "Sounds like you are saying…" are great ways to reflect back.
- Ask questions to clarify certain points. "What do you mean when you say…?" or "Is this what you mean?"

4. Defer judgment.

Interrupting is a waste of time. It frustrates the speaker and limits full understanding of the message. If you don't agree with the speaker's view, wait till you hear the full story or till the end during the question and answer period to bring your viewpoint. It's the speaker who had been asked to present.

- Allow the speaker to finish.
- Don't interrupt with counterarguments.

5. Avoid negative mannerisms, but respond.

Everyone has a mannerism. If a mannerism is encouraging and brings positive response, do it often. Unfortunately, some mannerisms are negative or distracting. These should be avoided.

- Tapping a pencil /pen or playing with a rubber band or other objects
- Continually looking at the watch
- Reading book or reports or texting/emailing
- Display arrogance or lack of interest

Active listening is a model for respect and understanding. It takes a lot of concentration and determination to be an active listener. Old habits are hard to break; it requires lot of discipline to do it.

Effective Team Meetings

Meetings are wonderful tools for generating ideas, expanding on thoughts and managing group activity. But this face-to-face contact with team members and colleagues can easily fail without adequate preparation and leadership. An effective communication is an enabler to make meetings successful.

To ensure everyone involved has the opportunity to provide their input, establish meeting rules — where, when and how long. This will allow all participants the time needed to adequately prepare for the meeting.

Once a meeting time and place has been chosen, ensure that the leader or coordinator is available for questions that may arise as participants prepare for the meeting. As the meeting leader, make a meeting agenda, complete with detailed notes.

In these notes, outline the goal and proposed structure of the meeting, and share this with the participants. This will allow all involved to prepare and to come to the meeting ready to work together to meet the *goals* at hand.

The success of the meeting depends largely on the skills displayed by the meeting leader. To ensure the meeting is successful, the leader should:

- Issue an agenda
- Start the discussion and encourage active participation
- Work to keep the meeting at a comfortable pace — not moving too fast or too slow
- Summarize the discussion and the recommendations at the end of each logical section
- Ensure all participants receive minutes promptly

Managing Meetings

Choosing the right participants is key to the success of any meeting. Make sure all participants can contribute; choose good decision-makers and problem-solvers. Try to keep the number of participants to a maximum of 12, preferably fewer. Make sure the people with the necessary information for the items listed in the meeting agenda are the ones who are invited.

As a meeting leader, work diligently to ensure everyone's thoughts and ideas are heard by guiding the meeting so that there is a free flow of debate with no individual dominating and no extensive discussions between two people. As time dwindles for each item on the distributed agenda, it will be necessary to stop the discussion, then quickly summarize the debate on that agenda item, and move on the next item on the agenda.

When an agenda item is resolved or action is agreed upon, make it clear who in the meeting will be responsible for this. In an effort to bypass confusion and misunderstandings, summarize the action to be taken and include this in the meeting's minutes.

Meetings are notorious for eating up people's time. Here are some ways of ensuring that time is not wasted in meetings:

- Start on time.
- Don't recap what you've covered if someone comes in late. It sends the message that it is OK to be late for meetings, and it wastes everyone else's valuable time.
- State a finish time for the meeting and don't over-run. If needed to over-run, ensure everyone is available to stay for a stated period.
- To help stick to the stated finish time, arrange your agenda in order of importance so that if you have to omit or rush items at the end to make the finish time, you don't omit or skimp on important items.
- Finish the meeting before the stated finish time if you have achieved everything you need to.

Minutes record the decisions of the meeting and the actions agreed. They provide a record of the meeting and, importantly, they provide a review document for use at the next meeting so that progress can be measured — this makes them a useful disciplining technique as individuals' performance and non-performance of agreed actions is given high visibility.

Problem Solving

There are a number of situations when we need to solicit good information from others. These situations include solving work problems, finding asset failure root causes, conducting safety investigations, seeking to help an employee on work performance, and finding out reasons for performance discrepancies.

Effective communication skills can be very useful in solving problems. Problems solving usually involves the following steps:

- Identify the problem.
- Analyze the problem and gather information.
- Generate potential solutions.

- Select and test the solution.
- Analyze the results.

Some of the tools used in problem-solving have been discussed earlier in the book; a few of them are summarized again:

- **Brainstorming.** This technique is used to encourage participation from each member of the team. Brainstorming helps to break people out of the typical mode of approaching things to produce new and creative ideas. It creates a climate of freedom and openness, which encourages an increased quantity of ideas.
- **Root Cause Analysis, Five Why's.** The objective of Root Cause Analysis is to find the fundamental cause for a problem. One way is to ask "Why?" five times or more to really get at the root of the problem.
- **Cause and Effect Diagrams.** This diagram is drawn to represent the relationship between an effect (the problem) and its potential causes. The diagram helps to sort out and relates the interactions among the factors affecting a process.
- **Pareto Charts.** A Pareto Chart shows a frequency distribution in which each bar on the chart shows the relative contribution of problems to the larger problem. It helps to identify where to focus energy to obtain the most positive impact.
- **Flow Charting.** A flow chart is a map that shows all the steps in a process. It helps in understanding the process and making sure all steps in the process are addressed.
- **Decision Matrix.** A Decision Matrix is useful when we are faced with making a difficult decision. The options or alternatives are listed in the left-hand column and the selection criteria are listed across the top row. Each of the options is rated against the selection criteria to arrive at the best logical decision.

12.3 Energy Conservation and Green Initiative

Introduction

Energy costs can have a significant impact on the financial performance of businesses. A recent poll taken by the National Association of Manufacturers (NAM) revealed that 93% of small and medium-sized manufacturing companies believe that higher energy prices are having a negative impact on their bottom line. In fact, the energy crisis of 2008 has caused many businesses to go under. As a result, organizations are reviewing and updating energy plans to reduce their energy usage.

Substantial opportunities exist to reduce energy wasted in the industrial, manufacturing, and service sectors. Organizations are affected directly by the energy cost of manufacturing products, maintaining operations – including offices and receiving raw materials — and delivering finished goods to the customers.

The environmental and climate impacts of energy usage are also rapidly becoming a major issue facing industry and society. Carbon dioxide (CO_2), a major greenhouse gas, is emitted to the atmosphere directly when fossil fuels are used on-site and indirectly when electricity is consumed (particularly when fossil fuels are used to generate the electricity). Identifying and eliminating energy waste offers a smart, efficient way to reduce energy costs and greenhouse gas emissions.

Energy use can have significant environmental impact in addition to climate change. On-site combustion of fuels in boilers, ovens, vehicles, and equipment can emit a variety of regulated pollutants, including carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxide (NO_x), particulate matter, volatile organic compounds (VOCs), and a variety of airborne toxins. Combustion pollutant emissions can affect worker health, and trigger the need for costly permitting, monitoring, and emission controls. More broadly, reducing air emissions from combustion activities can help protect neighboring communities and public health. Storage and handling of fuels and spent fuel also pose a variety of worker health, safety, and environmental costs and risks, even in the absence of spills.

Energy is a vital and often costly input to most production processes and value streams. Think unnecessary energy usage as another "deadly waste," and develop plans to eliminate or reduce it to achieve energy and environmental excellence. Benefits of Energy Management are:

- Reduced operating and maintenance costs
- Reduced vulnerability to energy and fuel price increases
- Enhanced productivity
- Improved safety
- Improved employee morale and commitment
- Improved environmental quality
- Reduced greenhouse gas emissions
- Remain below air permitting emission thresholds
- Increased overall profit

Energy usage is often viewed as a necessary support cost of doing business, and energy-efficiency efforts can sometimes have difficulty competing for organizational attention with other operational needs. By linking energy management to Environmental / Green and Lean activities, energy-reduction efforts can be tied more directly to process improvement efforts that are regarded by senior managers as being vital to business success.

Energy Reduction and Process Improvement Strategies

Many energy efficiency best practices can be implemented without extensive analysis or planning. In plant operations, several strategies can be employed to reduce energy usage such as:

- **Total Productive Maintenance (TPM).** Incorporate energy reduction best practices into day-to-day autonomous maintenance activities to ensure that equipment and processes run smoothly and efficiently.
- **Right-Sized Equipment.** Replace oversized and inefficient equipment with smaller equipment tailored to the specific needs of manufacturing.
- **Plant Layout and Flow.** Design or rearrange plant layout to improve product flow while also reducing energy usage and associated impacts.
- **Standard Work, Visual Controls, and Mistake-Proofing.** Sustain and support and energy performance gains through standardized work procedures and visual signals that encourage energy conservation.

In addition to explicitly using process methods to target energy wastes, facilities can take advantage of other opportunities for energy savings to install energy-efficient equipment, switch to less polluting fuel sources, and design products to use less energy. To be most effective, energy saving efforts should be proactive, strategic, and systematic to establish an energy management system that aligns with and supports the organization's initiatives to achieve the greatest improvements in operational, energy, and environmental performance.

Identifying and eliminating energy waste through process improvement including Lean / Green initiative can improve an organization's ability to compete in several ways. For example, reducing the energy intensity of production activities and support processes directly lowers recurring operating costs with direct bottom line and competitiveness impacts.

There are three steps involved in developing an energy planning and management roadmap appropriate to any organization,

1. **Initial Assessment.** Consider the opportunities, risks, and costs associated with strategic energy management.
2. **Design Process.** Understand the organization's energy needs and identify the best way to establish an energy management plan.
3. **Evaluate Opportunities.** Identify and prioritize energy-related improvement opportunities, such as energy-efficiency actions, energy-supply options, and energy-related products and services.

Energy Sources and End Usage

The predominant energy sources used in industry are natural gas and electricity. Industry also uses other energy sources, such as fuel oil, for producing heat. Some facilities have on-site co-generation, where they combust a fuel (e.g., natural gas, waste oil, or scraps) to produce heat and electricity. Understanding the energy end usage —what work we use the energy to do—reveals more useful information to identify opportunities for improving efficiency and reducing costs. In an office setting, end-uses primarily include heating, ventilating, and air conditioning (HVAC), lighting, and operation of appliances and computers. In an industrial plant, energy usage is in:

- Process equipment operation
- Process heating and cooling
- Transportation
- Heating, ventilating, and air conditioning (HVAC)
- Lighting

Process heating accounts for 53 percent of direct energy end usage at industrial facilities, while machine drives and motors account for another 22 percent, according to a recent study by NAM.

Consider targeting a facility's energy efficiency efforts on three key end usages that are likely to account for a significant portion of facility's energy use. The following end usage typically has energy savings opportunities:

- Process heat
- Machine drives and motors
- Leaks — air, water, and other gases

In addition, HVAC systems, and lighting may be good end usages to target.

Understanding the costs of energy use can raise awareness of the potential value of identifying and eliminating energy waste. The costs of energy use are not always visible to production/operations managers because they are rolled up into facility overhead costs, rather than assigned to production areas. Explicitly tracking costs associated with individual processes or equipment can encourage energy conservation.

One of the primary data sources for energy cost data is a facility's utility electric bill. Utility bills often include the following types of data:

- **Consumption Charges.** Electricity is charged based, in part, on the amount of electricity used (in kilowatt-hours, kWh) in a billing period. The per kilowatt-hour rate for electricity may vary based on the time of year (e.g., winter or summer season) and the time of day (peak or off-peak hours).
- **Demand Charges.** For many electricity customers, there will be a demand charge (per kilowatt) in the bill that is based on the peak electricity used each month averaged over a short time period (e.g., 15 minutes). A facility may pay more for demand costs than consumption costs, although the two costs may be a single line item in the utility bill.
- **Fuel Costs.** For natural gas and other fuels, facility may be charged for the amount of fuel received and a delivery charge for the transportation and delivery of the fuel. Fuel charges may vary seasonally and they are also based on the amount consumed.

Walkthrough Practice to Observe Energy Usage

Walkthrough assessment and observing processes as they actually run at a facility can be a simple, but effective way to identify waste and find improvement opportunities. During the walkthrough, look for signs of unnecessary or inefficient energy use. Remember to take an IR camera and an Ultrasonic leak detector gun to identify hot/cold spots and leaks. Also, ask questions, such as:

Motors and Machines

- Are machines left running when not in operation? If so, why?
- Are energy efficient motors, pumps, and equipment used?
- Are motors, pumps, and equipment sized according to their loads? Do motor systems use variable speed drive controls?

Compressed Air

- If compressed air is used, do we notice any leaks in the compressed air system? When was last air leak audit performed?
- Do compressed air systems use the minimum pressure needed to operate equipment?

Process Heating

- Are oven and process heating temperatures maintained at higher levels than necessary?

Facility Heating and Cooling

- Are work areas heated or cooled more than necessary?
- Do employees have control over heating and cooling in their work areas?
- Are exterior windows or doors opened to adjust heating and cooling?

Lighting

- Is lighting focused as we need it?
- Is lighting controlled by motion sensors in warehouses, stor age areas, and other areas that are intermittently used?
- Are energy-efficient fluorescent light bulbs used?

Energy Audits and Measuring Energy Usage

While a walkthrough is an excellent way to identify and fix energy wastes that are readily apparent, we may be leaving energy savings on the table unless we examine energy use more closely. Two strategies for learning more about its use include:

1. Conduct an energy audit to understand how energy is used — and possibly wasted — across facility.
2. Measure the energy use of individual production and support processes.

An energy audit, sometimes referred to as an energy assessment, is a study of the energy end uses and performance of a facility. Energy audits can range in complexity and level of detail, from a simple audit involving a facility walkthrough and review of utility bills, to a comprehensive analysis of historical energy use and energy-efficiency investment options. Energy audits allow managers to compare a plant's energy use to industry benchmarks and to identify specific energy savings opportunities.

In many locations, local utilities provide energy audit services for free or at reduced cost.

Operational Strategies to Reduce Equipment Energy Waste

As we had discussed in Chapter 7, Total Productive Maintenance (TPM) is an operational practice that builds upon established equipment-management approaches and focuses on team-based maintenance that involves employees at every level and function. The objective of TPM is to:

- Build a robust organization by maximizing production system efficiency (overall effectiveness).
- Address the entire production system lifecycle and build a shop floor-based system to prevent all losses. It aims to eliminate all accidents, defects, and breakdowns.
- Involve all departments, from production to development, maintenance, and administration.
- Reduce loses to zero.

Increased equipment operating efficiency reduces energy waste. When machines are optimally tuned to accomplish the desired work, energy inputs are most efficient. TPM's emphasis on equipment efficiency can lead to reduced costs, increased productivity, and fewer defects. TPM focuses on the six big losses that lead to equipment inefficiency:

- Breakdowns
- Setup and adjustment loss
- Idling and minor stoppages
- Reduced speed
- Defects and rework
- Start and yield losses

Eliminating or minimizing the six losses maximizes the productivity of equipment throughout its lifetime. With proper equipment and systems maintenance, organizations can reduce manufacturing process defects and save an estimated 20 percent or more in energy costs.

Autonomous maintenance, a pillar of TPM, already captures a number of best practices, such as cleaning, proper lubrication, and standardized maintenance practices. Use of checklists — such as the Energy-Reduction Checklists for Combustion, Steam Generation, and Process Heating Systems to identify opportunities to decrease energy consumption with autonomous maintenance — is a good practice to adopt. The following checklists are based on best practices compiled by the U.S. Department of Energy's (DOE) Energy Efficiency and Renewable Energy Division:

Combustion Systems

- Operate furnaces and boilers at or close to design capacity.
- Reduce excess air used for combustion.
- Clean heat transfer surfaces.
- Reduce radiation losses from openings.
- Use proper furnace or boiler insulation to reduce wall heat losses.
- Adequately insulate air or water-cooled surfaces exposed to the furnace environment and steam lines leaving the boiler.
- Install air preheat or other heat recovery equipment.

Steam Generation Systems — Boilers

- Improve water treatment to minimize boiler blow down.
- Optimize de-aerator vent rate.
- Repair steam leaks.
- Minimize vented steam.
- Implement effective steam trap maintenance program.

Process Heating Systems

- Minimize air leakage into the furnace by sealing openings.
- Maintain proper, slightly positive furnace pressure.
- Reduce weight of or eliminate material handling fixtures.
- Modify the furnace system or use a separate heating system to recover furnace exhaust gas heat.
- Recover part of the furnace exhaust heat for use in lower-tem perature processes.

Replace Over-Sized and Inefficient Equipment with Right-Sized Equipment Process Improvement often results in the use of right-sized equipment to meet production needs. Right-sized equipment is designed to meet the specific needs of manufacturing or an individual process step, rather than the processing needs for an entire facility. For example, rather than relying on one large paint booth or parts cleaning tank station to service all painting and degreasing needs for a facility, Lean principles typically lead organizations to shift to right-sized paint and degreasing stations that are embedded in manufacturing cells.

In conventional manufacturing, equipment/systems often are over-sized to accommodate the maximum anticipated demand. Because purchasing a new, large piece of equipment is often costly and time-consuming, engineers often design in additional "buffer capacity" to be sure that the equipment does not constrain the production. For example, a fan system is usually oversized. Ways in which it could be correctly sized to reduce energy are:

- **Use smaller, energy-efficient motors.** Right-sizing a 75-horsepower (hp) standard efficiency motor with a 60-hp energy-efficient motor will reduce motor energy consumption by about 25 percent or more.
- **Reduce fan speed by larger pulleys.** Replacing an existing belt-driven pulley with a larger one will reduce its speed, saving energy costs. Reducing a fan's speed by 20 percent reduces its energy consumption by 50 percent.
- **Use of static pressure adjustment for variable air volume (VAV) systems.** Reducing static pressure in VAV system reduces the fan power consumption. By gradually reducing the static pressure set point to a level low enough to keep occupants comfortable, energy consumption can be reduced.

Design Plant Layout to Improve Flow and Reduce Energy Usage

Process improvement focuses on improving the flow of product through the production process. Arrange equipment and workstations in a sequence that supports a smooth flow of materials and components through the process, with minimal transport or delay. The desired outcome is to have the product move through production in the smallest, quickest possible increment (one piece). Improving the flow of product and process inputs can significantly reduce the amount of energy required to support a production process.

An example of a good design is to use large pipes and small pumps rather than small pipes and big pumps. Optimizing the whole system together will lead to dramatically decreased operating costs. The objective is to minimize friction losses.

The following is a list of some best practices suggestions that have been applied by many organizations successfully to reduce their energy costs:

- Set standards and specifications that optimize energy efficiency in equipment, operations and plant investments.
- Design buildings and processes to minimize use of energy.
- Conduct energy audits of all existing sites, identify energy-conservation opportunities, and develop plans to implement solutions.

- Install new, more energy-efficient motors on machines.
- Use variable speed drives on pumps and fans.
- Ensure adequate staffing and funding to implement needed conservation and energy-savings activities.
- Promote energy-conservation habits among employees.
- Install energy-efficient lighting fixtures.
- Install motion sensor switches in offices and conference rooms, cutting the amount of power used to light those rooms.
- Place exterior lighting fixtures on timer controls.
- Mandate that computers be turned off during non-use periods of two hours or longer
- Install skylights to reduce lighting loads.
- Implement an energy management system that automatically regulates energy needs throughout buildings.
- Lower thermostats for heat from 68 to 63 degrees, and for cooling from 72 to 78 degrees.
- Turn off lights when not in use, especially rooms that aren't used all the time like bathrooms, storage rooms, lunch rooms, and extra offices.
- Set copy machines and printers on power saver mode.
- Use a dimmer light setting at night.
- Shut down all computers and unnecessary office equipment at night.
- Replace indoor lighting systems with energy efficient lamps and ballasts.
- Replace lighted exit signs with LED exit signs, which use less energy than standard bulbs.
- Installed room occupancy sensors in many locations to turn off lights and save power whenever possible.
- Install state of the art lighting upgrades, which will help decrease energy consumption while keeping lighting at optimum levels.
- Conduct a "building tune-up" of facilities, ensuring that all possible energy conservation practices are being observed.

Green Energy and Green Initiative

Green energy is a term used to describe sources of energy that are considered to be environmentally friendly and non-polluting, such as geothermal, wind, and solar power. These sources of energy may provide a remedy to the alleged effects of global warming and certain forms of pollution. They are generally more expensive than traditional energy sources, but can be purchased with the help of government subsidies.

Several working definitions used for green energy include:

- An alternate term for renewable energy
- Energy generated from sources which do not produce pollu tants (e.g., solar, wind, and wave energies)
- Energy generated from sources that are considered environ mentally friendly (e.g., hydro (water), solar (sun), biomass (landfill), or wind)
- Energy generated from sources that produce low amounts of pollution
- Energy that is produced and used in ways that produce relatively less environmental impact

Green Building is another initiative to reduce energy usage and environmental impact. Green Building Initiative (GBI) challenges state governments to demonstrate leadership in energy efficiency and environmental responsibility in state buildings, while also reducing the impact state facilities have on climate change.

GBI requires the state to reduce grid-based energy usage in its buildings 20% by 2015, and, in so doing, reduce greenhouse gas emissions associated with the production of fossil fuel-based power required to operate those same buildings.

LEED (Leadership in Energy and Environmental Design)

A LEED-certified building uses significantly less energy and water, and produces fewer greenhouse gas emissions, than conventional construction. Many state and federal government are mandating to meet a minimum of LEED Silver certification for new construction and major renovations of facilities larger than 10,000 square feet. In addition, smaller buildings are being designed to meet LEED standards.

12.4 Lean Management and Maintenance

"Lean" is a new buzzword. Words such as lean production, lean manufacturing, lean maintenance, lean management, lean enterprise, and lean thinking have been abundantly discussed in literature in the last few years. But what does "Lean" really mean?

As the word says, Lean means literally — LEAN. We all need to be lean to become or stay healthy. We need to get rid of fat — waste which we carry around with us. Similarly, in our work environment, we need to be efficient and effective (in others words, lean) to stay healthy and survive in today's competitive environment. Appropriate use of tools is necessary to be efficient and effective, and to ultimately create value for our customers. In fact, many subject matter experts and authors are saying the same mantra — get rid of the waste.

For example, Kevin S. Smith, President of TPG Productivity, Inc., states, *"Lean is a concept, a methodology, a way of working; it's any activity that reduces the waste inherent in any business process."*

In their famous book *Lean Thinking*, James P. Womack and Daniel T. Jones write that the critical starting point for lean thinking is value. Value can only be defined by the ultimate customer. It's only meaningful when expressed in terms of a specific product (a good or a service, and often both at once) that meets the customer's needs at a specific price at a specific time.

Lean Background

Lean philosophy or thinking is not new. At the turn of the century, Henry Ford, founder of the Ford Motor Company, was implementing lean philosophy. Of course he didn't use the word lean at that time.

John Krafcik, a Massachusetts Institute of Technology (MIT) researcher in the late 1980s, coined the term *Lean Manufacturing* while involved in a study of best practice in automobile manufacturing. The MIT study had examined the methodology developed at Japanese auto giant Toyota under the direction of production engineer Taiichi Ohno, who later became known as the father of TPS, the Toyota Production System, a model of lean system. At the end of World War II, with Toyota needing to improve brand image and market share, Ohno reputedly turned to Henry Ford's classic book, *Today and Tomorrow* for inspiration. One of Ford's guiding principles had been the elimination of waste.

Ohno is credited with developing the principles of lean production. His philosophy, which focused on eliminating waste and empowering workers, reduced inventory and improved productivity. Instead of maintaining resources in anticipation of what might be required for future manufacturing, as Henry Ford did with his production line, the management team at Toyota built partnerships with suppliers. In effect, under the direction of Ohno, Toyota automobiles became made-to-order. By maximizing the use of multi-skilled employees, the company was able to flatten their management structure and focus resources in a flexible manner. Because of this, Toyota was able to make changes quickly; they were often able to respond more quickly to market demands than their competitors.

To illustrate the lean thinking, Shigeo Shingo, another Japanese Lean and Quality expert, observed that only the last turn of a bolt actually tightens it — the rest is just movement. This ever finer clarification of waste is a key to establishing distinctions between value-added activity, waste, and non-value-added work. Non-value adding work is a waste that must be removed. Ohno defined three broad types of waste: Muri, Mura, and Muda. These are three key Japanese words in lean terminology.

- Muri: Overburden
- Mura: Unevenness
- Muda: Waste, non-value-added work

Muri is all the unreasonable work that an organization imposes on workers and machines because of poor organizational design, such as carrying heavy weights, unnecessary moving, dangerous tasks, even working significantly faster than usual. It is pushing a person or a machine beyond its natural limits. This may simply be asking a greater level of performance from a process than it can handle without taking shortcuts and informally modifying decision criteria. Unreasonable work is almost always a cause of multiple variations.

Mura is a traditional Japanese term for unevenness, inconsistency in physical matter or human spiritual condition. Mura is avoided through JIT systems which are based on little or no inventory, by supplying the production process with the right part, at the right time, in the right amount, and first-in, first out component flow. Just in Time systems create a "pull system" in which each sub-process withdraws its needs from the preceding sub-processes, and ultimately from an outside supplier. When a preceding process does not receive a request or withdrawal, it does not make more parts. This type of system is designed to maximize productivity by minimizing storage overhead.

Muda is traditional Japanese term for activity that is wasteful and doesn't add value or is unproductive.

The original seven *muda* are:

1. **Transportation.** Moving material and parts that are not actually required for process.
2. **Inventory.** No extra inventory should be in the system. All components, work-in-progress, and finished product not being processed are waste.

3. **Motion.** People or equipment moving or walking more than required to perform the work are waste.
4. **Waiting.** Waiting for the next step or something. Time not being used effectively is a waste.
5. **Overproduction.** Production ahead of demand or need.
6. **Inappropriate Processing.** Produce only what is needed and when needed with well-designed processes and assets.
7. **Defects.** The simplest form of waste involves components or products that do not meet the specification. They lead to additional inspections and defects that must be fixed.

First, Muri focuses on the preparation and planning of the process, or what work can be avoided proactively by design. Next, Mura focuses on how the work design is implemented and the elimination of fluctuation at the scheduling or operations level, such as quality and volume. Muda is then discovered after the process is in place and is dealt with. It is seen through variation in output. It is the role of management to examine the Muda in the processes and eliminate the deeper causes by considering the connections to the Muri and Mura of the system. The Muda and Mura inconsistencies must be fed back to the Muri, or planning, stage for the next project.

Lean requires the use of a set of tools that assist in the identification and steady elimination of waste. Examples of such tools are Brainstorming, Cause and Effects Analysis, Five S, Kanban (pull systems), Poke-yoke (error-proofing), Pareto Analysis, and Value Stream Mapping.

Lean Maintenance

Much has been written and talked about lean concepts in manufacturing, but what about lean maintenance? Is it merely a subset of lean manufacturing? Is it a natural spinoff from adopting lean manufacturing practices? Lean maintenance is neither a subset nor a spinoff. Instead, it is a prerequisite for success as a lean organization. Can we imagine lean JIT concepts to work without having reliable assets or good maintenance practices? Of course, we want maintenance to be lean — efficient and effective — without waste. Lean maintenance has nothing to do with thinning out warm bodies, or more directly, reducing maintenance resources. Rather, it has to do with enhancing the value-added nature of our maintenance and reliability efforts.

In maintenance, our customers are inherently internal to our organization — they are our operations / production departments. One of the primary responsibilities of maintenance is to provide plant capacity to its customers. Let's face a fundamental truth: We can't be successful with Lean manufacturing if we don't have reliable assets, reliable machines. Lean maintenance is not performing lean (less) corrective or preventive actions. It is not about facilitating a poor maintenance program. Maintenance customers expect maintenance and reliability programs to be optimized — effective and efficient, and fully supporting the need to operate at designed or required capacity reliabily.

The majority of maintenance activities revolve around systems and the processes that move people, material, and machine together such as preventive maintenance programs, predictive maintenance programs, planning and scheduling, computerized maintenance management systems, and store room and work order systems. We need to apply the principles of Lean to these maintenance programs and processes to drive out the non-value added activities.

Value stream mapping for key maintenance processes to identify non-value added activities need to be performed. It will be a good practice to create a current and future state of the maintenance processes in order to develop a plan to reduce and eliminate wasteful activities. In developing the current- and future-state maps of maintenance process, we must also assess the skills and knowledge of our maintenance personnel. A poorly-skilled person operating within a great system will produce poor results. Likewise, if we have the good preventive maintenance program, yet our PMs are poorly structured and designed, our PMs will achieve poor results. Therefore we need to optimize PM using tools such FMEA/RCM to give new life to our efforts.

The endless pursuit of waste elimination is the essence of lean maintenance. Eliminate waste by understanding the seven wastes discussed earlier in relation to maintenance. Identify where they exist and eliminate them. For example:

1. **Transportation.** Plan and provide materials and tools to reduce the number of extra trips to the store room to hunt for the right parts.
2. **Inventory.** Eliminate or minimize extra inventory in the system. Keep only the right material / parts / tools in the store room.
3. **Motion.** Minimize people movement by improved planning.
4. **Waiting.** Minimize waiting for the next step — another skilled person or part — by improved planning and scheduling.

5. **Overproduction.** Develop optimized PMs, FMEA/RCM based; perform root cause analysis to reduce failures, etc.
6. **Inappropriate Processing.** Use the right tools and fixtures to improve maintenance processes.
7. **Defects.** Eliminate rework and poor workmanship. Educate / train maintenance personnel appropriately.

Most organizations, even without proclaiming a Lean maintenance effort, might actually be engaged in the very activity that will get them there. For example, TPM and Lean share many traits. Standardization, 5 S, and mistake-proofing are just a few other examples. More importantly, TPM recognizes that the operator is just as responsible for asset reliability as the maintenance person. One of the key objectives of TPM is to eliminate the six major losses: breakdown, set up and adjustments, idling and minor stoppages, operating at reduced speeds, defects, and reduced yield. It is to these losses that we employ CMMS, work orders, planning and scheduling, and other system tools in order to mitigate them.

Our challenge going forward is to identify activities which don't add value to maintenance and reliability. Use tools to analyze problems (waste in the system), develop value-added solutions, and implement practices that have been discussed earlier in the book to become a lean organization.

12.5 Safety and Reliability

Several reliability and safety experts have observed that reliable plants are safe plants and safe plants are reliable plants. Furthermore, safe and reliable plants are usually profitable plants. Safety and reliability have historically been considered two separate elements of the production /operations system. Recently, both have been proven to be increasingly interrelated. In fact, safety is treated as the most important attribute in reliability analysis.

Ron Moore, a leading M&R expert and noted author, writes that there is a strong correlation — a correlation coefficient of 0.87 — between OEE / Uptime and accident (injury) rate per 100 employees. Overall Equipment Effectiveness (OEE), a product of equipment availability, quality, and performance, is a key indicator of reliability and operational performance. This conclusion is based on his observation and data from many plants that he had visited for his consulting tours.

A study by Batson, Ray, and Quan reported in the October 2000 issue of *Reliability Magazine* made similar observations. Their studies indicated that in the organizations where maintenance performance ratings have increased tenfold, injury frequency and severity have been reduced tenfold, in a nearly linear fashion.

Another observation reported in PIMA's June 2003 conference in New York referred to a study by a major Pulp and Paper company that found the company was 28% more likely to have an incident when maintenance work was reactive versus work that was planned and scheduled before execution. The author's own observations conclude a strong correlation between safety incidents / injuries and reactive maintenance. In a reactive situation, we might not take the time we should to plan and think before we take action. The urgent nature of reactive work also requires maintenance personnel to take risks they shouldn't be taking.

These observations strongly imply that organizations that are reliable with excellent maintenance practices will have lower injury rates. The same behavior and practices that improve plant operations and reliability also reduce injuries. Therefore, those organizations with high reliability and safe operations will be more productive and profitable.

Creating a Safe Culture and a Culture of Care

When Rosanne Danner, Vice President of Development for DuPont Safety Resources, was asked to describe her definition of a safety culture, she noted that she had once asked the same question to one of her colleagues. He replied, "What people do when no one is watching." There is certainly some truth to that. But if we step back and think about the word culture, it's about what people do, how they interact, how they live day to day. When we apply it to safety, it moves beyond simply being a program and becomes part of one's being. A Safety culture doesn't just stay at the organization or workplace. It goes home with us. It's part of the fabric of who we are. For example, when I drive home, I automatically put on my seatbelt. I also make sure that my passengers wear their seatbelts. I do not use my cell phone when I am driving. These actions are all a natural extension of following a safety culture at work.

As we have discussed, Reliability is not just the responsibility of the maintenance department, but is for everyone in the organization including operator, planner, supervisor, designers, store person, and purchasing manager — and includes the organization's leadership team. Similarly, safety is not just the responsibility of the safety department. It is for every one of us to be responsible for our own and our co-worker's safety. Leadership plays a key role in ensuring that we understand our role in keeping the workplace safe. Safety and reliability — a good stewardship of our resources — should be part of organization's core values. The leadership should become a role model by doing, not just talking.

Consider a scenario where we are walking to attend a meeting in the plant area. On the way, we find a puddle of water or oil spill on the shop floor near an assembly area. Should we stop and take care of this spill before somebody else slips and gets hurt? We are already late to the meeting. We could just keep going and hope that somebody will take care of this spill. What should we do?

It's simple. STOP! Get somebody to take care of this potential hazard before proceeding to the meeting. Yes, we will be late. It's OK. Apologize to the meeting group and tell them the truth — the reason for being late. Also, on the way back, ensure that the hazard has been taken care of and somebody is finding out its root cause. That's safety culture.

Instituting a safety culture must begin at the top of the organization. However, all employees have a responsibility to follow procedures and think about how they do their work. Usually, we start with an organization in the reactive stage, where employees are reacting to incidents instead of thinking about how to prevent or eliminate them. Once employees begin to view safety as something important to them and something which they value, they move to the independent stage. This is where they are practicing safety because they want to do it, not because they are being told to do it. The ultimate goal is the interdependent stage when every employee is looking out for the other. It's a "brother's keeper" mentality. At this stage, any employee should be comfortable to call out a safety issue to the point where they will stop a production line if they see a problem, or challenge a manager who, for example, isn't wearing a hard hat.

The State of Montana has done a unique thing to create a safety culture. A Safety Culture Act was enacted in 1993 by the Montana state legislature to encourage workers and employers to come together to create and implement a workplace safety philosophy. The intent of this act is to raise workplace safety awareness to a preeminent position in the minds of all Montana's workers and employers. It becomes the responsibility and duty of the employers to participate in the development and implementation of safety programs that will meet the specific needs of their workplace — thereby establishing a safety culture that will help to create a safe work environment for all future generations of Montanans.

The Act requires every employer to establish, implement, and maintain a safety-based training program which shall, at a minimum:

1. Provide each new employee with a general safety orientation containing information common to all employees and appropriate to the business operations, before they begin their regular job duties. It is recommended that orientation is to contain both oral and written instruction including information on:
    - Accident and hazard reporting procedures
    - Emergency procedures
    - Fire safety
    - First aid
    - Personal protective equipment
    - Work site hazards
2. Provide job- or task-specific safety training appropriate for employees before they perform that job or task without direct supervision. It is recommended that the training should:
    - Include specific safety rules, procedures, and hazards
    - Identify the employer's and employee's responsibilities regarding safety in the workplace
    - Be conducted by personnel knowledgeable of the task being trained
    - Be conducted when the program is established, when employees job assignments change, when new substances are introduced to the workplace, and when a new hazard is identified
3. Offer continuing regular refresher safety training. It is recommended that the training should:
    - Be held as is appropriate, but at least annually
    - Contain material to maintain and expand knowledge and awareness of safety issues in the workplace
4. Provide a system for the employer and their employees to develop an awareness and appreciation of safety through tools such as newsletters, periodic safety meetings, posters, and safety incentive programs.
5. Provide periodic self-inspection for hazard assessment when the safety program is implemented, new worksites are established, and thereafter as is appropriate to the business operations, but at least annually, which:
    - Identifies hazards and unsafe work practices or condi tions
    - Identifies corrective actions needed
    - Documents corrective action taken

6. Include documentation of performance of activities listed in (1) through (5) above. This documentation must be kept by the employer for three years. It is recommended that the documentation should include:
    - Date, time, location and description of training, inspec tions, and corrective actions
    - List of participants, i.e. inspectors, trainers, participants
7. Policies and procedures that assign specific safety responsibilities and safety performance accountability. It is recommended that policies and procedures should:
    - Include a statement of top management commitment to the safety program
    - Encourage and motivate employee involvement in the program
    - Define safety responsibilities for managers, safety per sonnel, supervisors, and employees
    - Be reflected in job descriptions and performance evaluations
    - Be communicated and accessible to all employees
8. Procedures for reporting, investigating, and taking corrective action on all work-related incidents, accidents, injuries, illnesses, and known unsafe work conditions or practices. It is recommended that procedures are non-punitive and include:
    - Provisions for timely and effective reporting
    - Recommendations and follow-up corrective action
    - Documentation
    - Signature requirements for reports, investigations, and corrective actions
    - Periodic evaluation of the procedure's effectiveness

A Safety Process Model

Adhering to a simple process model is another highly effective component of an overall strategy for improving the safety in an organization. The model below focuses on four aspects of safety:

- **Leadership.** As stated earlier, leadership involvement is important. Leaders must lead and support the safety process wholeheartedly. They must communicate the importance of safety as well as the value and respect they have for the people who work for them.

- **Personnel.** Investing in people is paramount to success. The best organizations will first seek to hire the right people and then develop their capabilities and skill sets. Be sure to include questions about safety as part of the hiring process, to gain an understanding of a prospective employee's knowledge of safety, and to communicate organization's commitment to safety.
- **Environment.** It's essential to ensure that the overall environment is safe, assets and systems are properly cared for, operating practices are adhered to, and engineering standards are followed. Conduct a design safety review of all equipment from inception and a full ergonomic review before installation and continue annually after that. Establish extensive inspection programs to ensure compliance and be on the lookout for new technologies to reduce risk.
- **Behavior.** Changing organizational behavior is what transforms an organization from good to world class. When passion for safety is driven by a leadership team, it filters down to the floor and will encourage workers to actively care about one another and fosters interdependence within the organization.

Turn Employees into Safety Leaders

To be successful, organizations should create career paths that turn employees into safety leaders by making sure that everyone is highly trained and motivated — not just to *succeed*, but to *exceed* expectations. Workers should be mentored, to help them contribute to the safety process. The organization should also develop an environment and culture that supports the belief that every employee can create and maintain a workplace free of illness and injury. The result of this investment will be establishing within workers a sense of ownership of the safety process and a shift within the organization from an independent to an interdependent culture. This can help drive employees to eliminate unsafe behaviors and conditions and to focus on eliminating injuries entirely, rather than just meeting regulatory requirements.

According to OSHA, when a company's safety culture is strong, "everyone feels responsible for safety and pursues it on a daily basis; employees go beyond 'the call of duty' to identify unsafe conditions and behaviors, and intervene to correct them."

Consider posting the following safety principles throughout the plant / facility to remind employees of the importance organization places on safety:

- Any person can and must confront unsafe behaviors and conditions. No one is authorized to disregard such a warning.
- No one is expected to perform any function or accept any direction that they believe is unsafe to themselves or others, or creates an unsafe situation, regardless of who directs such an action.
- Anyone who feels that a process is unsafe will shut down that process and work with appropriate team members to create a safe situation.

An organization's greatest asset is its employees, and protecting them from illnesses or workplace injuries is critical to success. Operating an injury-free facility is no longer a dream. In many workplaces, it has become a reality — and not just for a year, but for several years running. Creating a workplace that is free of illness and injury begins with one crucial decision: making safety a core value.

Many organizations such as DuPont, Kimberly-Clark, Harley-Davidson, General Mills, and Jacobs Engineering have created a safety culture in their organizations. They have been able to reduce their injury and incident rate below 1 per 100 employees. In fact, their goal is zero — beyond zero. Some of them the have a new initiative called "Beyond Zero" to create a "culture of care." These results can be attributed to a culture that embraces safety and empowers employees to maintain a commitment to safety in everything they do. The key to this success is establishing a safety-based culture that starts at the top.

According to DuPont's Rosanne Danner, of the most common reasons organizations fail to develop a safety culture are:

1. **Lack of commitment from leadership and management.** A safety culture has to start with the CEO setting the right vision of where we want to be. That person needs to say, "This is how we do work." Safety must be part of measuring performance. It's not profitability or safety — it's both. That commitment must extend down to line management. If line managers see something that is unsafe, and they don't call it out, and it happens a second time, then it becomes an acceptable way to do work. It becomes the new standard. If something is viewed as not being important to the manager, then employees won't pay attention to it.
2. **Inconsistency in how and where safety is applied.** Manage - ment must put in place the right procedures and consistently follow them. They may start all internal and external meetings with a safety message or contact. This speaks to being constantly

aware of a person's surroundings and thinking through actions that a person would take in a variety of possible scenarios.

3. **Loss of focus.** Instituting a safety culture is not an overnight proposition. If it is done correctly, we may see a change in injury rate sooner, but it will take time to make it ingrained in an organization. We can't let the quick results trick us into losing our focus for the long term.

Implementing a safety policy for any organization should be a top priority. Employees should be encouraged to report any unsafe conditions right away and should be trained how to react in an emergency. The primary goal of a workplace safety policy is to establish the expectation that it is the responsibility of all employees to create and maintain a safe work environment.

12.6 Systems Engineering and Configuration Management

Imagine that a craft person we have sent to repair an asset finds out that the new spare won't fit or the new motor has a different footprint (frame size) from what's documented in the CMMS system. Suppose we have ordered a special purpose machine and, upon installation, it does not do what it is supposed to do. In both cases, the system requirements or configurations were not documented properly or they were misinterpreted. Has this happened in your plant? If we had followed systems engineering and configuration management practices appropriately, we would have minimized such issues.

Systems Engineering (SE) is an interdisciplinary engineering management process that evolves and verifies an integrated, life-cycle balanced set of system solutions that satisfy customer needs. Systems engineering management is accomplished by integrating three major categories:

- A product development phase that controls the design process and provides baselines that coordinate design effort
- A systems engineering process that provides a structure for solving design problems and tracking requirements flow through design process
- Life cycle integration that involves customers in the design, building, and installation (including commissioning) process, and ensures that the product developed is viable throughout its life.

Configuration management (CM), a component of SE, is a critical discipline in delivering products that meet customer requirements and that are built according to approved design documentation. It addition, it tracks and keeps updated system documentation which includes drawings, manuals, operations/maintenance procedures, training, etc.

CM is the methodology of effectively managing the life cycle of assets and products in the plant. It prohibits any change of the asset's form, fit, and function without a thorough, logical process that considers the impact proposed changes have on life cycle cost.

Systems Engineering (SE)

The term systems engineering can be traced back to Bell Telephone Laboratories in the 1940s. The need to identify and manipulate the properties of a system as a whole — which in complex engineering projects may greatly differ from the sum of the parts' properties — motivated the Department of Defense, NASA, and other industries to apply this discipline.

The purpose of SE is to provide a structured but flexible process that transforms requirements into specifications, architecture, and configuration baselines. The discipline of this process provides the control and traceability to develop solutions that meets customer needs. Life cycle integration, a key component of SE process, is achieved through integrated development — that is, concurrent consideration of all life cycle needs during the development process.

The key primary functions of systems engineering support the system (product):

- **Development.** This function includes the activities required to evolve the system from customer needs to product /process solutions.
- **Build/Construction/Manufacture.** This function includes the fabrication and construction of unique systems and subsystems.
- **Deployment/Fielding.** These activities are necessary to deliver, install, check out, train, operate, and field the system to achieve full operational capabilities.
- **Operations.** The user (system owner) operates systems safely as designed (not to be abused).
- **Support/Maintenance.** This area includes activities necessary to provide operational support including maintenance, logistics, and materials management.

- **Disposal.** It considers the activities necessary to ensure that once the asset or system has completed its useful life, it is removed in a way that meets all applicable regulations.
- **Training.** These are the activities necessary to achieve and maintain the knowledge and skill levels for efficiently and effectively performing operations, maintenance, and other support functions.
- **Verifications.** These activities are necessary for evaluating the progress and effectiveness of the system's processes, and to measure specification (requirements) compliance.

Systems engineering is a standardized, disciplined management process for developing system solutions. It provides a methodical approach to system development in an environment of change and uncertainty. SE ensures that the correct technical tasks get done during the development through planning, tracking, and coordinating. Systems engineering covers the "cradle to grave" life cycle process.

Configuration Management (CM)

Configuration management is a field of management that focuses on establishing and maintaining the consistency of product performance, and its functional and physical attributes with its requirements, design, and operational information throughout its life.

Configuration management was first developed by the U.S. Department of Defense in the 1950s as a technical management discipline. The concepts have been widely adopted by numerous technical management models, including systems engineering, integrated logistics support, Capability Maturity Model Integration (CMMI), ISO 9000, project management methodology, and product lifecycle management.

Configuration management is used to maintain an understanding of the status of complex assets with a view to maintaining the highest level of serviceability for the lowest cost.

Complex assets such as automobiles, aircraft, and major capital equipment sometimes consist of hundreds to thousands of parts. In addition, there are related tooling, fixtures, gauges, templates, test equipment, and control software. It is estimated that a part may undergo ten engineering changes or more over its life. This suggests that an organization may evaluate and process many hundreds to thousands of engineering changes for a complex system. It takes a significant amount of effort to keep baseline and documentation current.

Over the life cycle of systems, the manufacturer, supplier, and owner must assure that the as-designed configuration at any point in time will satisfy functional requirements and that the hardware and software actually delivered (as-built configuration) corresponds to the approved as-designed configuration. The CM emphasis should be continued during O&M phase to ensure all documentation is current. As a result, the configuration management effort required for a complex system is significant. Usually, computerized systems such as CMMS/EAM/ERP may be required to support configuration management if an organization is to avoid being drowned in a sea of paper and non-value-added administration.

An organization's configuration management program includes an evaluation process which identities, examines, and selects assets / systems, computer software, and documents that will be part of the CM program. The evaluation process also provides for periodic assessment of the program elements throughout the lifetime of the program.

Typical examples of documents included in a configuration management program include:

- System descriptions
- Drawings
- Special studies and reports including safety inspections or investigations
- Operations and maintenance procedures, guidelines, and acceptance criteria
- Instrument and control set points
- Quality assurance and quality control documents
- Vendor/suppliers manuals
- Regulatory requirements, codes, and standards
- Modification including capital project packages
- Component and part lists
- Specifications and purchase orders information for major and critical assets
- Asset/system performance and maintenance records
- Welding qualification records
- Pressure vessels/systems integrity and inspection records
- Design criteria/requirements
- Operations/maintenance training records

Documents and records should be continuously updated to include all approved changes and should be accurately reflected in output documents such as drawings, system descriptions, specifications, and procedures.

A cautionary note: the CM program will cost significant resources to implement. Therefore, organizations must evaluate what documents and records should be part of the CM program based on the asset's complexity and criticality.

Rules for Configuration Changes

The discipline required with complex products such as defense systems provides an excellent basis for considering rules related to configuration changes. As a prerequisite to configuration control, it is important to understand the classes of change and the implications of these changes on the bill of material structure. Class I changes affect an item's fit, form, or function. These are changes that affect an item's specifications, weight, interchangeability, interfacing, reliability, safety, schedule, cost, etc. Class II changes are changes to correct documentation or changes to hardware not otherwise defined as a Class I change.

Another concept that will affect the implementation of changes is interchangeability, which is defined as when two parts possess such functional and physical characteristics as to be equivalent in performance, reliability, and maintainability. These parts should be able to be exchanged one for another without selection for fit or performance and without alteration of the item itself or of adjoining items.

A Class I change is implemented by changing an item's part number. This is done because, by definition, the change affects fit, form, or function. The new version of the item is no longer interchangeable with the old item.

Change control should ensure that changes to the assets are correctly identified, screened, designed, evaluated, implemented, and recorded. This includes both permanent and temporary changes.

A well-defined and managed configuration management process is required to ensure the following:

- All relevant documents are consistent with the asset's specific design requirements
- Changes which take place to the design during the life cycle of the asset are based on current, specific knowledge of the configuration of the asset's hardware, software, and design documents
- Procurement of materials and spare parts is consistent with the current design configuration

- Operating and maintenance procedures are based on the current design configuration
- Plant documentation accurately reflects the current asset configuration

The CM program also helps to be in compliance with ISO 9000 requirements.

Standards

The following is a list of CM-related standards that may be referred for developing an effective program:

- ANSI/EIA-649-1998 National Consensus Standard for Configuration Management
- ISO 10007:2003 Quality management systems; Guidelines for configuration management
- GEIA Standard 836-2002 Configuration Management Data Exchange and Interoperability
- IEEE Std. 828-1998 IEEE Standard for Software Configuration Management Plans
- MIL-STD-973 Configuration Management (canceled, but still good reference)

In summarizing, a CM program in an organization should be concerned with following:

- Reviewing proposed design changes
- Controlling the installation of permanent and temporary changes
- Commissioning and testing the changes to ensure that they meet the design intent
- Ensuring that the assets are being operated and maintained in the appropriate configuration
- Maintenance of documents and records

This will ensure that the organization remains in the appropriate configuration with the right and current documentation during its operating life cycle.

Configuration management affects the entire organization. Every plant and facility must have an effective configuration management program to eliminate or mitigate the negative impact of uncontrolled, undocumented changes in the configuration of its assets. Enforcing a logical, disciplined process to evaluate, design, procure, implement, operate, and maintain modifications to major and critical assets eliminates most of the excessive maintenance cost caused by poor records .

12.7 References and Suggested Reading

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Answer Key and Explanations

Q. 1	a
Q 2	b
Q. 3	a
Q. 4	a
Q. 5	a
Q. 6	a
Q. 7	a
Q. 8	a
Q. 9	a
Q. 10	a
Q. 11	a
Q. 12	a
Q. 13	a
Q. 14	a
Q. 15	a
Q. 16	a
Q. 17	a
Q. 18	b
Q. 19	a
Q. 20	b
Q. 21	b
Q. 22	a
Q. 23	a
Q. 24	b
Q. 25	b
Q. 26	c
Q. 27	b
Q. 28	a
Q. 29	a
Q. 30	a
Q. 31	b
Q 32	a
Q. 33	b
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Q. 45	a
Q. 46	b
Q. 47	b
Q. 48	c
Q. 49	c
Q. 50	b
Q. 51	b
Q. 52	d
Q. 53	b
Q. 54	c
Q. 55	a

1. Best Practices are practices that are defined and applied by an organization. They may or may not be proven, but results are found to be acceptable

Answer: a — True

A best practice is a business function, a practice, or a process, that is considered superior to all other known methods. It's a documented strategy and approach used by the most respected, competitive, and profitable organizations. A best practice when implemented appropriately should improve performance and efficiency in a specific area.

2. Maintainability is measured by PM schedule compliance.

Answer: b — False

Maintainability is defined as ease of maintenance; it's primarily measured by Mean Time to Repair (MTTR). See more details in Chapter 6.

3. All maintenance personnel's time is covered by work orders.

Answer: a — True

All maintenance personnel's time should be counted and documented in CMMS to ensure all repair and maintenance costs are accurate. See more details in Chapters 3 and 4.

4. Operations and Maintenance work as a team to achieve improved OEE.

Answer: a — True

OEE is calculated as Availability X Performance X Quality. Operations and Maintenance both impact this metric and need to work together as a team to achieve higher OEE. See more details in Chapter 7.

5. Best practices would indicate that 90% or more of all maintenance work is planned.

Answer: a — True

It's good practice to plan 90% or more work. Planned work costs 2–3 times less than reactive work. See more details in Chapter 4.

6. 100% of PM and PdM tasks should be developed using FMEA /RCM methodology.

Answer: a — True

All PM / PdM tasks should be developed using FMEA / RCM methodology. This ensures cost effective and correct tasks to mitigate certain risks and to find failures before they fail. See more details in Chapter 3 and 8.

7. Utilization of Assets in a world-class facility should be above 98%.

Answer: a — True

Assets cost money to procure and maintain. They should be utilized 98% or better to get high ROI. Of course, our M&R task is to ensure their availability; we need some time to perform maintenance too. See more details in Chapter 4 and 9.

8. 100 % of maintenance personnel's (craft) time should be scheduled.

Answer: a — True

100 % of maintenance personnel, specifically craft available hours, should be scheduled. Scheduling compliance analysis should provide opportunity to reduce/eliminate waste and improve productivity. See more details in Chapter 4.

9. Time-based PMs should be less than 20% of all PMs.

Answer: a – True

It's a good and cost effective practice to do more run/cycle-based and condition-based PM. It's good practice to have calendar-based PMs 20% or less. If assets are operating 24/7, calendar-based PM could be a higher percentage. See more details in Chapter 3.

10. The 10% rule of PM is applied on critical assets.

Answer: a — True

This rule implies that time-based PM must be accomplished in 10% of the time frequency or it is out of compliance. Many organizations use this metric "PM Compliance" as a measurement of their maintenance department's performance, which is a good metric. But, we need to ensure that critical assets are being maintained properly at right time, within 10% of time frequency. See more details in Chapter 3.

11. Most emergency work orders should be written by production.

Answer: a — True

Most emergency work orders should be written by the production–operators. Operators are on the shop floor all the time and they should know what needs to be fixed to meet production schedule. However, maintenance should also write WO if emergencies arise. Emergency and unscheduled work cost many times more than routine scheduled work. See more details in Chapters 4 and 7.

12. It is common practice for Operators to perform PMs.

Answer: a — True

This is true assuming the organization is deploying TPM as one of the best practices. Under TPM philosophy, operators do perform PMs and support maintenance. See more details in Chapter 7.

13. P-F interval be applied to visual inspections.

Answer: a — True

Yes, the primary objective is to detect a fault, or find the start of one, and correct it before it fails. Detection can be visual or by using predictive technologies. See more details in Chapter 8.

14. Understanding of a P-F interval curve should help in optimizing PM frequency.

Answer: a — True

Yes, the primary objective is to detect a fault, or find the start of one, and correct it before it fails. The PM frequency should be less than the P-F interval. See more details in Chapter 8.

15. The best method of measuring the Reliability of an asset is by counting downtime events.

Answer: a — True

Yes, Reliability is measured by MTBF, which is operating time divided by the number of failures, or downtime events. See more details in Chapter 6.

16. The primary purpose of scheduling is to coordinate maintenance jobs for greatest utilization of the maintenance resources.

Answer: a — True

It's true. The goal is to get all work completed as scheduled. See more details in Chapter 4.

17. What percentage of your assets should be ranked critical based on the risk to business?

Answer: a — Less than 20%

We need to take care of all the assets cost effectively. However, we don't have unlimited money to do that. We need to do everything possible to ensure all critical assets are being maintained properly. It has been found that on average 20% +/-5% should be considered critical assets as a good practice. See more details in Chapters 3 and 4.

18. Vibration monitoring can detect uniform impeller wear.

Answer: b — False

Uniform wear will not create any unbalance, hence no vibration. See more details in Chapter 8.

19. Understanding the known and likely causes of failures can help design a maintenance strategy for an asset to prevent or predict failure.

Answer: a — True

If we understand the failure mechanism — how a part or component can fail — we could develop a mitigating maintenance strategy to prevent failure. See more details in Chapters 8 and 11.

20. Reliability can be improved easily after a maintenance plan has been put into operation.

Answer: b — False

Reliability is a design attribute. It means that reliability is based on how an asset is designed — with what type of components and their configurations. A PM plan can't change the basic (inherent) reliability unless the components are changed or redesigned with more reliable, higher MTBF parts. See more details in Chapters 6 and 8.

21. What percentage of maintenance work should be proactive?

Answer: b — 85%

The proactive work is defined as all work minus unscheduled/unplanned work. We know that the planned and scheduled work cost less than unscheduled, reactive work. We have found that it's good or best practice to have proactive work 85% or more. See more details in Chapters 3 and 4.

22. MTBF is measured by operating time divided by the number of failures of an asset.

Answer: a — True

MTBF is mean time between failures. To calculate it, divide the operating time by the number of failures, or downtime events. See more details in Chapter 6.

23. Maintenance cost will decrease as reliability increases.

Answer: a — True

Initially, when we are starting an M&R improvement plan, maintenance cost may go up, but eventually it should come down as reliability of assets increases. See more details in Chapter 3 and 6.

24. The "F" on the P-F Interval indicates that equipment is still functioning.

Answer: b — False

In the "P-F" interval curve, F stands for failure and P stand for potential failure. See more details in Chapter 8.

25. A rule of thumb is that, on average, an experienced planner can plan work for how many craft people?

Answer: b — 15

On average, an experience planner should able to plan work for about 15 +/- 5 craft people, depending upon type of work. Usually 15 is a good number. See more details in Chapter 4.

26. Which of the following is not a primary objective for implementing Planning and Scheduling?

Answer: c — Mesh the production schedule and the maintenance schedule

It's not a P&S job to mesh maintenance and production schedules. However, they may use production schedules to improve their schedule or to identify conflicts. See more details in Chapter 4.

27. The best method of measuring the reliability of an asset is by

Answer: b — MTBF

Reliability is measured by MTBF, which is operating time divided by the number of failures. MTTR is a measure of maintainability. See more details in Chapters 6 and 9.

28. With the exception of emergency work orders, P&S will benefit all maintenance work.

Answer: a — True

The P&S should benefit all maintenance work. Planned and scheduled work cost much less and work get accomplished in a timely manner. See more details in Chapter 4.

29. Leading KPIs predict results.

Answer: a — True

The leading indicators are process indicators and they lead to the results. For example, PM compliances and back log are leading indicators. See more details in Chapter 9.

30. The 6th S in the 6 S (also called 5 S plus) process stand for safety.

Answer: a — True

The original Five S (5 S — sort, set, shine, standardize, and sustain) is a basic, systematic process for improving productivity, quality, and housekeeping. Lately, a 6th S has been added to focus on safety too. 5 S was originated in Japan. See more details in Chapter 7.

31. RCM stands for:

Answer: b —

See more details in Chapter 8.

32. The objective of RCM is to preserve functions.

Answer: a — True

See more details in Chapter 8.

33. An MRO storeroom shouldn't be stocking parts used for emergencies.

Answer: b — False

The FMEA/RCM analysis should provide us with details of failure modes and what part we need to stock. However, in some cases, it may be cost effective not to stock if parts can be procured or made available locally in couple of hours. See more details in Chapter 5.

34. The inventory turnover ratio for MRO store should be

Answer: a — Less than 2

Yes, it should be less than 2 for maintenance-related spares. Mostly these are long lead and costly "A" type inventory. See more details in Chapter 5.

35. PM compliance is a lagging KPI.

Answer: b — False

It's not true. Lagging indicators are the results. Leading indicators are process indicators and they lead to the results. For example, PM compliances and back log are leading indicators.

36. Quality is one key components of OEE.

Answer: a — True

OEE = Availability X Performance X Quality. See more details in Chapter 7.

37. Reliability and Maintainability can only be designed in.

Answer: a — True

Reliability and Maintainability are design attributes. It means that reliability and maintainability depend upon how the asset is designed and with what type of components and configurations. A maintenance strategy can't change the basic (inherent) reliability. However, training the work force in repair techniques and providing the right tools will improve the asset availability. See more details in Chapter 6.

38. Creating a reliability culture from a reactive mode can be accomplished in a short period of time if enough resources are made available.

Answer: b — False

Changing culture takes a long time. We can't change a sustainable culture overnight. It's a journey that takes many years and is not dependent on recourses; it's time. See more details in Chapter 2.

39**. Karl Fischer's Coulometric titration method is an effective technique to determine metallic content (in PPM) in an oil sample.**

Answer: b — False

Karl Fisher's method is used for determining water content — Parts per Million (PPM) in an oil sample. See more details in Chapter 8.

40. An IR thermography windows is an effective method to satisfy NFPA 70E arc flash requirements

Answer: a — True

IR thermography windows are being used effectively to detect any hot spots or potential problems in electrical cabinets, switchgears, etc., and help in meeting NFPA -70 E arc flash requirements. See more details in Chapters 8 and 12.

41. FMEA is applicable to only assets currently in use.

Answer: b — False

FMEA can apply to any asset whether in use or not. In fact, its good application is in new systems being designed/ developed to identify potential failure modes. See more details in Chapters 8 and 11.

42. RCM methodology can't be used effectively on new systems being designed.

Answer: b — False

RCM can be used on new or "in use" systems. In fact, it's a good application for new system under development to use RCM methodology to identify potential failure modes and to develop an effective PM plan. See more details in Chapter 8.

43. Properly training the M&R workforce can increase asset and plant availability.

Answer: a — True

Training the M&R workforce in application of new tools/techniques will reduce repair time, resulting in higher availability. See more details in Chapters 10 and 11.

44. TPM is a type of maintenance performed by the operators.

Answer: a — True

Total Productive Maintenance (TPM) is another maintenance strategy where an operator does some maintenance, sometimes called first level, e.g., changing filters, minor adjustments, etc., and becomes part of the maintenance crew in supporting major repairs. See more details in Chapter 7.

45. Lagging KPIs are the result of a process.

Answer: a — True

Lagging indicators are the results. For example, Maintenance cost and availability are lagging indicators. See more details in Chapter 9.

46. EOQ improves the inventory turn ratio.

Answer: b — False

EOQ (Economical Order Quantity) calculates the optimum order quantity to optimize inventory cost. It does not impact the inventory turnover ratio. See more details in Chapter 5.

47. New incoming oil from the supplier is always cleaned and ready to be used.

Answer: b — False

It has been found that the incoming oil is not usually clean and does not meet cleanliness requirements. Most organizations are establishing oil cleaning systems to clean all incoming oil to ensure that new oil meets cleanliness requirements. See more details in Chapter 8.

48. Which phase of asset life cycle has the highest cost?

Answer: c — O&M

O&M phase usually has the highest cost in an asset's life cycle. See more details in Chapter 6.

49. Most of the maintenance costs are fixed during

Answer: c — Design

Most maintenance costs get fixed during the design phase. See more details in Chapter 6.

50. RCM provides best results when used

Answer: b — Design

RCM should be used in the design phase to get maximum benefits. See more details in Chapters 6 and 8.

51. How soon can we restore an asset is measured by

Answer: b — MTTR

MTTR is a measure of how soon can we bring the asset back to operations. See more details in Chapter 6.

52. Availability is a function of

Answer: d — Uptime and downtime

Availability is defined by uptime divided by uptime plus downtime. See more details in Chapter 6.

53. The failure rate of a component / asset can be calculated by knowing

Answer: b — MTBF

Failure rate is the inverse of MTBF. See more details in Chapter 5.

54. Most benefit of a Failure Mode and Effect Analysis occurs during

Answer: c — design

FMEA should be performed during the design phase to identify failure mode and those that could be eliminated or their impact reduced or mitigated cost effectively. See more details in Chapters 6 and 11.

55. PM schedule compliance should be equal or greater than 95%.

Answer: a — True

High (95% or better) PM schedule compliance will catch potential failures before they happen, thereby reducing the unexpected breakdowns. See more details in Chapters 3 and 4.

Supplemental Glossary

See index for all Key Terms defined within each chapter

ABC Classification. Classification of inventory to give varied level of attention in order to optimize inventory cost.

Asset List / Register. A register of physical assets — equipment, machines, buildings, etc. — usually with information on manufacturer, vendor, specifications, cost, warranty, and status.

Cycle Counts. An inventory accountability strategy where counting and verification of stock item quantities is done continuously based on a predetermined schedule and frequency.

Deferred Maintenance. Maintenance tasks that can be or have been postponed from a schedule.

Economic Order Quantity (EOQ.) A quantity of an item that should be ordered at one time to get the lowest possible combination of inventory carrying and ordering costs.

Life Cycle Cost (LCC). All costs associated with the phases of a life cycle, including design–development, build, operate, maintain, and disposal. It is the total cost of ownership for the life of the asset.

Pareto Principle. Critical few, often about 20 percent of items, failures, assets, parts, etc., that should receive attention before the insignificant many, which are usually about 80 percent. It's also known as 80/20 rule.

INDEX

Index Terms **Links**

Key Terms defined within each chapter are highlighted in **boldface**.

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