Industrial Maintenance & Reliability Reference Guide

How to Implement Reliability Centered Maintenance at Your Facility

By John S. Mitchell

INTRODUCTION

Reliability Centered Maintenance (RCM) is publicized as the latest "silver bullet" solution to developing an optimum maintenance program. Many organizations have and are expending large amounts of time and resources implementing RCM to gain assurance that their systems and assets have maximum production availability. While some companies do not experience the vast improvement that may have been expected, most will comment that the requirements and discipline necessary to implement RCM have many positive non-monetary benefits.

This paper addresses five considerations to assure the time and resources expended on RCM gain maximum value:

- Since there always will be more opportunities for improvement than resources, the first systems and assets selected for RCM should be those that constitute greatest risk (threat) to production availability and cost objectives. Greatest value and return is gained by a prioritized implementation taking largest threats (and opportunities) first.
- Ultimately, any successful reliability improvement program must improve availability and reduce cost. Care must be exercised to assure that RCM is directed to increasing reliability and uptime while simultaneously reducing the need for maintenance.
- In a production/manufacturing facility more than ten years old, most probable failure modes have likely occurred at some time in the past. Failure history and current estimates of potential problems should be used as a reasonable predictor of future performance.
- In some cases, an improved maintenance program by itself is incapable of meeting availability and cost objectives of a system or asset. Material and component upgrades, even outright replacement, may be required.
- The RCM program must be kept evergreen. Conditions, as well as the probability and consequences (risk) of failure, may change necessitating corresponding changes to the asset management process.

Background

In the late 1980s early 1990s Reliability Centered Maintenance (RCM), developed for commercial aircraft, was introduced to industry as a rigorous scientific means on which to develop and base a maintenance program. Today, RCM is promoted as the "silver bullet" solution to maintenance optimization. A standard defines the RCM process (SAE Standard JA1011 "Evaluation Criteria for Reliability Centered Maintenance (RCM) Processes") and there are many books and articles promoting the necessity and virtues of RCM. As a carrot, promises of a positive Return On Investment (ROI) in months are not uncommon. On the stick side of persuasion, some have gone so far to state that a failure to implement RCM may have legal ramifications in the event of mechanical malfunction.

Amid all the fanfare there are less than successful programs and people urging caution. As an example of the latter, if you are a third or fourth quartile performer in terms of maintenance costs, should RCM be the first program implemented to begin the journey to competitive excellence? If you are experiencing a large number of bearing failures, which should be accomplished first, RCM or identifying the principal cause of failure and implementing focused corrective action such as a comprehensive lubrication program? How about the opposite end of the scale? Is it an effective use of resources for a first quartile performer to implement RCM on all systems and assets to improve performance even further?

The answer to both the questions may be the same – RCM is a powerful tool when used selectively to improve performance. Facilities at both the top and bottom of the performance scale can gain by utilizing RCM very selectively to devise an optimum management strategy for low performing systems and assets.

For a mid sized facility, applying RCM to all equipment and systems will probably cost approximately $500,000. At that level of investment, RCM will have to show a minimum of $750,000 improvement within 18 months or so. Those considering RCM must recognize that the RCM process must return an attractive ROI.

And these observations lead into the first factor that should be considered to assure success of an RCM program:

RCM – Some Factors for Success

Prioritized Implementation

Accomplishing an RCM analysis requires a large investment of resources. A typical medium sized system may require a couple of man months, possibly more, to step through all the essential elements of RCM defined by the SAE Standard and formulate an optimum maintenance program. In this situation it makes sense to prioritize systems and assets so that entities with the greatest known and probable deficiencies are addressed first. That action will assure that scarce resources are applied selectively to those systems and assets that will gain greatest value and return.

A good case can be made that preceding the RCM process with a risk ranking of systems and assets will assure that time and resources gain greatest value. The risk ranking is designed to identify systems and assets that have greatest risk—threat to operational requirements and cost objectives—and hence opportunity for improvement. Stated another way, every facility has systems and assets that are behaving well and seldom, if ever, experience problems. Whether it is design, installation, the operating context, to use a term from RCM, or the current maintenance program, these systems and assets don't need immediate attention.

Risk ranking will provide assurance that initial efforts are directed to "problem children" with greatest potential for recovering value in terms of both availability and cost. Likewise, resources are not expended on systems and assets that are performing well. To assure greatest opportunities are addressed first and the number is manageable, the process must be forced to categorize no more than 10% to 15% of the total systems and assets in the highest risk group.

In one case, a criticality assessment identified approximately 1,600 systems out of a total of about 2,200 as critical first priority for RCM. After about a year of effort by a dozen or so reliability engineers RCM had been completed on approximately 200 systems—13% of the total considered most critical. At that point the program was more or less abandoned due to priorities, resource availability and uncertain return. Did the 200 RCM analyses that had been completed cover the highest priority systems or address the most threatening potential problems with greatest value recovery? No one knew—that step hadn't been accomplished.

A Successful Program Must Improve Availability and Reduce Cost

Today, most companies in North America have gone as far as they can by reducing numbers of personnel. Outsourcing labor may reduce cost, however, that too quickly reaches a floor. The only way to permanently reduce maintenance costs is by increasing reliability so there is less maintenance required. The success of this concept can be observed in modern automobiles where maintenance requirements have been designed out. As a result, today's automobiles are far more reliable with maintenance a fraction of what was required only fifteen to twenty years ago.

Industrial facilities contemplating RCM recognize that a maintenance program must increase availability and reduce cost. A methodology that adds work, such as more PM's with added cost and / or downtime to accomplish, probably won't prove acceptable over the long term. Added work risks later abandonment to "reduce costs" and/or improve "production availability." Thus, the improvement program must not only ask what should be done to "predict or prevent each failure" but also what can be done to eliminate the failure altogether. Heavy emphasis should be placed on the latter.

Use History as a Basis

Classical RCM was developed as a means to scientifically formulate a safe and effective maintenance program for systems and assets that had never been operated. Today, most industrial systems and assets on which RCM is applied have ten or more years operating history. Over that period, those responsible for operation and maintenance should have a reasonable idea of past and potential problems, causes and consequences. While not all inclusive, history should certainly be considered when implementing RCM.

There may be concern that records are inaccurate, history is largely anecdotal and causes have never been formally determined through a rigid Root Cause Failure Analysis (RCFA). Despite these concerns, there are ways to determine the frequency of problems. For example, bearing purchase records will provide an accurate basis for determining Mean Time Between Failure (MTBF) independently of maintenance records. If this examination reveals a particularly low MTBF (less than about 48 months) taking a good look at the lubrication program with the idea of optimization from assuring proper lubricant, receipt and storage, issue and application through disposal is probably a better investment of resources than RCM. Since most failed motors are either repaired by an outside service shop or replaced, purchasing records will be an accurate indicator of motor repair costs.

If a system or asset has operated essentially trouble free for an extended period, longevity would indicate the existing maintenance program (whatever it may be) is more or less adequate. In the risk ranking mentioned in the first section, the successful system or asset would probably fall well below the threshold set for initial application of RCM. If applied at all to systems and assets with a successful history, RCM should ask what if any improvements are necessary rather than beginning with a blank sheet of paper. Major changes from the program that produced success should be closely evaluated.

If extending overhaul interval is one objective of the reliability improvement process, history must be examined even more closely to determine whether unexpected conditions were found and corrected at prior overhauls that could cause a forced outage with an extended overhaul interval.

Additionally, one would hope that RCM is not the first or only method applied to mature systems and assets. For example, can the application, effectiveness and value potential of Condition Based Maintenance (CBM) be ascertained if there is no institutional knowledge of the technology, its application or the results that can be expected for the facility's systems and assets? Should an RCM program be necessary to justify an optimized lubrication program?

Upgrades, Even Replacement, May be Required to Meet Pbjectives

Most facilities operate some systems and assets that are not suited for the current service. They may have been designed incorrectly, for service conditions that never occurred or conditions that occur so infrequently that design compromises weren't required. Additionally, service conditions might have changed since design and installation.

As an example, deep well centrifugal pumps were installed on the outlet from a large atmospheric tank. The deep well pumps proved very unreliable, failing after approximately six months service, and were costly to repair. A design review disclosed that the deep well design was deemed necessary in the event the tank, filled with a gas-saturated liquid, had to be pumped empty. In practice, neither condition occurred. Looking at realistic operating requirements the solution was evident—replace the deep well pumps with far more reliable in-line pumps. Although the in-line pumps weren't capable of meeting the original design specifications they proved more than adequate for the service, far more reliable and much less costly under actual conditions.

Another example: Variable speed DC motors were very unreliable and costly to maintain. Replacing the DC motors with variable frequency AC motors essentially eliminated the problems. The AC motors proved orders of magnitude more reliable and far less costly to maintain.

In both the cases cited, would an RCM program have led to a conclusion to replace assets that had proven unreliable or would it have concocted a more extensive and costly maintenance program to mitigate design deficiencies? Those conducting RCM must assure that the process will consider design and material improvements as well as outright replacement as an alternative course of action compared to more extensive maintenance.

Keeping the RCM Program Evergreen

In most industries the operating context may change over time for both systems and assets. The necessity for greater availability (less excess capacity), more intense competition (demanding reduced costs), operating at higher rates (business/market demands), changing operating mode (e.g., base load generating to peaking), changes in the composition of raw materials (refining and petrochemical industries) and more restrictive environmental regulations are a few examples.

All of the above can significantly alter the risk (probability and consequences) of failures and downtime. Thus, a maintenance program that was highly effective when implemented may lose effectiveness over time as conditions and priorities change. For this reason, the risk rank of systems and assets, assumptions used in the reliability improvement process and the maintenance program itself must be periodically reviewed to assure the activities are most effective and meet latest requirements.

Streamlined RCM

Streamlined RCM has been given a bad name, primarily by purists who don't have to deal with real world priorities and the limitations on time and resources present in an operating facility. If implemented properly Streamlined RCM can be a substantial time saver while at the same time preserving the benefits of classical RCM.

The most generally accepted form of streamlined RCM applies the principles outlined in the preceding paragraphs:

- Initial prioritization based on a risk rank to establish sequence of application and thereby assure greatest value.
- Maintenance templates utilized to assure that vital experience is fully utilized, minimize redundant effort required for essentially identical assets.

- Existing monitoring and maintenance processes considered in the analysis.
- Periodic audits performed to assure the program is effective and meets latest requirements.

The first point, initial prioritization, has been covered. To emphasize the point made earlier, initial prioritization will assure that the first systems and assets subjected to RCM are those where the program will do the most good and create the greatest benefit. Furthermore, whatever is accomplished, and very few facilities will have the luxury of being able to subject every system and asset to RCM, initial prioritization will assure the most pressing threats and opportunities are addressed within resource availability.

While classical RCM requires constructing a maintenance strategy from the ground up, the use of readily available maintenance templates can save a considerable amount of time. The use of templates also assures a full range of industrial experience is considered in the development of a maintenance program for common assets such as motors, pumps, fans and gears. In each case, common maintenance procedures can be utilized effectively with variations to accommodate design details such as sealed or lubricated bearings, the environment (operating context) including ambient and operating temperature, exposure and aggressive contaminants. Variations in any of these areas may dictate additional maintenance routines, altered intervals and expanded surveillance.

It is also true that every system and asset has some existing maintenance program. This may range from reactive, repair on failure to condition based maintenance. In any case there will be a failure pattern or perhaps absence of failures. If purely reactive maintenance has been the norm, the failure history should provide valuable input as mentioned earlier. Similarly, there should be a history of conditions discovered and repairs initiated as a result of condition monitoring. All existing information combined with a risk / threat analysis will be considered in the Streamlined RCM process.

Finally, the necessity of maintaining the program evergreen has been mentioned. The Streamlined RCM process institutionalizes periodic audits, reevaluation of conditions and conclusions to assure that the program and results delivered continue to meet requirements. Have availability and mean time between repair increased? Have costs been reduced? If the answer to both is yes, your program is a success.

SUMMARY AND CONCLUSIONS

Reliability Centered Maintenance (RCM) is a powerful process. It forces discipline into the maintenance process, requires that vital supporting documentation such as P&ID's (Process and Instrumentation Drawings) and Bills Of Materials (BOMs) are up to date. Properly implemented RCM will arrive at an optimum maintenance strategy meeting operating requirements and conditions. With that stated there are a couple of caveats to assure an RCM program gains greatest value and benefits:

- Very few production facilities will have sufficient time and resources to subject every system and asset to RCM. Creating maximum value requires prioritization to assure that RCM is applied, in order, to systems and assets with the greatest need and opportunity for improvement. When RCM is accomplished in priority order, implementers are assured that whatever RCM can be applied within constraints will do the most good.
- For most operating organizations history is valuable guidance of what can/might occur in the future. Operators and mechanics can pinpoint systems and assets that give the most trouble. Similarly, assets and systems with a good history are likely to remain tame in the future. When going through the RCM process, history is a good guide to indicate the most likely failures and failure modes. Here again, prioritization is key.
- Recognize that reducing the need for maintenance is a key element of meeting objectives for increased availability and reduced cost. People implementing RCM should be on the alert for improvements in materials, added and/or upgraded components and even outright replacement to eliminate rather than mitigate problems. While increased maintenance may accomplish the latter, only the former will meet all cost and availability objectives—permanently.
- An RCM program must be viewed as a continuing process rather than a one-time event. As conditions change, requirements will also change. Periodic audits and continuing improvement are the hallmarks of a successful reliability improvement program and a vital step on the road to excellence.

Effective Data Collection for Thorough Failure Analysis

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Abstract

In order to remain competitive, the goals of industrial plant facilities must include high levels of machine reliability, in order to reduce downtime, extend equipment life, reduce repair costs, improve equipment efficiency, reduce capital costs, increase productivity and maintain employee morale and satisfaction.

Maximum equipment and process reliability cannot be achieved or maintained if the plant is continually subjected to breakdowns, inadequate or incorrect repair procedures, or recurring failures.

This paper will outline the eight causes of poor reliability and will present processes by which the combined use of analytical trouble shooting and thorough failure analysis can prevent or eliminate breakdowns and failures which cause poor machine reliability.

Introduction to Equipment Reliability Concepts

"When you focus on cost reduction, reliability gets worse, but focus on reliability and costs go down." - Richard (Doc) Palmer

What is machinery reliability? What are the factors associated with reliability? Who is responsible for understanding and controlling these factors? What are machinery failures? How are machinery and component failures related to reliability?

The questions relating to machine reliability are many. The answers are not so simple, however in this paper we will discuss the issues of reliability and the factors associated with it. We will look at the process of establishing (or improving) the reliability of machinery, so that we can gain such worthwhile results as increased productivity, reduced downtime, extended equipment or plant life, reduced capital costs, reduced machinery repair and improved equipment efficiency.

These improvements, increased by just a few percentage points, can mean the difference between success and failure of the company.

What Is Reliability?

"Reliability is the ability of a component within a machine system, a system within a piece of machinery or the machine itself, to perform a required function under a specific set of conditions for a specified period of time." It is usually expressed as the MTBF, or mean time between failure.

What Is a Failure?

Since it should be obvious that reliability ends (or is reduced) whenever a failure occurs, it is necessary to understand what is considered a failure. "A failure is any incident or condition that causes an industrial plant, manufactured product, process, material or service to degrade or become unsuitable or unable to perform its' intended function or purpose safely, reliably and cost effectively."

It is only reasonable then to believe that if we are to attempt to eliminate failures which reduce reliability, it is essential that we must completely and thoroughly understand how and why failures occur, so that we can apply strategies and techniques to avoid them in the first place.

Many people believe that failure is directly related to the age of the machinery in question. This is a mistaken and costly assumption. Recent research into the probability of equipment failure and its corresponding age have shown some surprising results. The research provided four major conclusions.

1. Failure isn't usually related directly to age or use, but rather to the operating conditions to which the equipment is subjected. Failures resulting from age or use might only be attributed to the fatigue life of the machinery or its components.
2. Failure isn't easily predicted unless condition monitoring is regularly and consistently applied, so restorative maintenance or replacement, based on time or use, won't normally help to reduce the failure odds.
3. Major overhauls or component replacements based on age can be a bad idea because you end up with a much higher over all life cycle cost which many people erroneously begin to believe is normal.
4. Major repairs or component replacements can actually cause an increase in premature equipment failure due to careless workmanship, rushing due to time constraints, or the use of improper methods, assembly procedures or incorrect specifications.

Many people fail to consider (or even understand), how the equipment design or operating conditions to which a machine or plant is subjected affect the equipment. In fact, the reliability of industrial machinery will be reduced by 50% or more, if extreme or unusual operating conditions are not taken into account. Machinery reliability problems (and subsequent premature failures) are directly associated with such conditions as:

1. Poorly designed machinery.
2. Improper modifications to machinery.
3. Excessive loads or speeds. Consider; if the load on a rolling element bearing is doubled, the bearing life will be reduced by up to 90%. If the speed on a rolling element bearing is doubled, the bearing life may be reduced by as much as 50%.
4. Excessive machine vibration. Consider; about 70% of machine vibrations are caused by mechanical looseness, misalignment and unbalanced conditions.
5. Extreme temperature conditions. Consider; a rolling element bearing operating at a temperature that continually exceeds 70º C (160º F), lubricated by mineral base EP oil, will fail prematurely.
6. Excessive contamination conditions. Consider; 70 – 80% of hydraulic system failures are directly caused by contaminated oil.
7. Poor operating practices,
8. Poorly designed or inadequately applied maintenance programs.

Who Is Responsible For Reliability?

By definition, there are two major elements of any organization that directly affect industrial or plant machinery. These two major elements are the machines themselves and the people who manage this machinery.

This must result in the conclusion that everyone in the organization is responsible for reliability; for without it, the plant will fail and the enterprise will not succeed.

The philosophy that everyone in the organization is responsible for machine reliability (and therefore the company's ultimate success) is frequently not understood (or even believed) by many people in today's industrial plants. Certainly the reliability of machinery and plant equipment will improve dramatically when everyone who is even remotely connected with the machinery begins to feel and act personally responsible for its care and maintenance.

Guidelines for Developing a Reliability and Failure Analysis Program

The reliability of machinery begins with the initial design, where operating conditions, life cycle costs, maintainability issues and preventive maintenance issues are considered. Next, the installation, commissioning, operation and maintenance strategies and procedures are selected and applied.

Once in operation, reliability is then affected by many things and conditions can be monitored by such strategies as condition monitoring and predictive maintenance. Corrective maintenance and modifications may be undertaken and carried out from time to time.

Finally, the life cycle of the machine ends with the decommissioning and disposal.

When establishing the reliability engineering and failure analysis programs for the equipment and machinery in your facility or plant, the following considerations must be taken into account.

Improving Machinery Reliability through Analytical Trouble Shooting and Root Cause Analysis; An Overview

Before one can correctly determine the root cause of any machinery failure or process defect, it is first absolutely necessary to understand the fundamental conditions and mechanisms which will ultimately lead to a component or system failure. According to Heinz Bloch, in his book, "Machinery Failure Analysis and Troubleshooting," all machinery failures belong to one or more of the following root cause failure classifications:

- Faulty design, either of the machine itself, or a component within the machine.
- Material defects, such as incorrect hardness or incorrect material.
- Processing or manufacturing deficiencies or errors.
- Assembly or installation defects.
- Off-design or unintended service conditions, often related to improper operating conditions, or the use of equipment in an application for which it was not designed.
- Maintenance deficiencies, such as neglect, improper procedures, incorrect specifications, inadequate maintenance task selection and/or inadequate task completion.
- Improper operation, such as poorly trained operators, inadequate operating procedures or exceeding operational capacity.

Once we have determined the primary root cause failure classification, we can now move on to determine the failure mechanism or initiating cause. Failure mechanisms or initiating causes can be grouped into four categories:

- Mechanical initiating causes would include such conditions as misalignment, excessive loads, ineffective sealing, etc.
- Tribological initiating causes include failures caused by inadequate but frequently fundamental requirements, such as incorrect lubricant quantity or quality, lubricant oxidation or contamination.
- Thermally initiating causes include the careless or excessive use of applied heat during assembly procedures, such as during bearing installation, or failures cause by extreme operating temperatures.
- Chemically initiated causes are those where failures will result when components come into contact with incompatible lubricants, process chemicals or corrosive gases. Chemically initiated failures may be caused by something as simple as water contamination which cam result in corrosion of components.

We can further break down the initiating causes into four distinct possibilities and how, when and where they might occur.

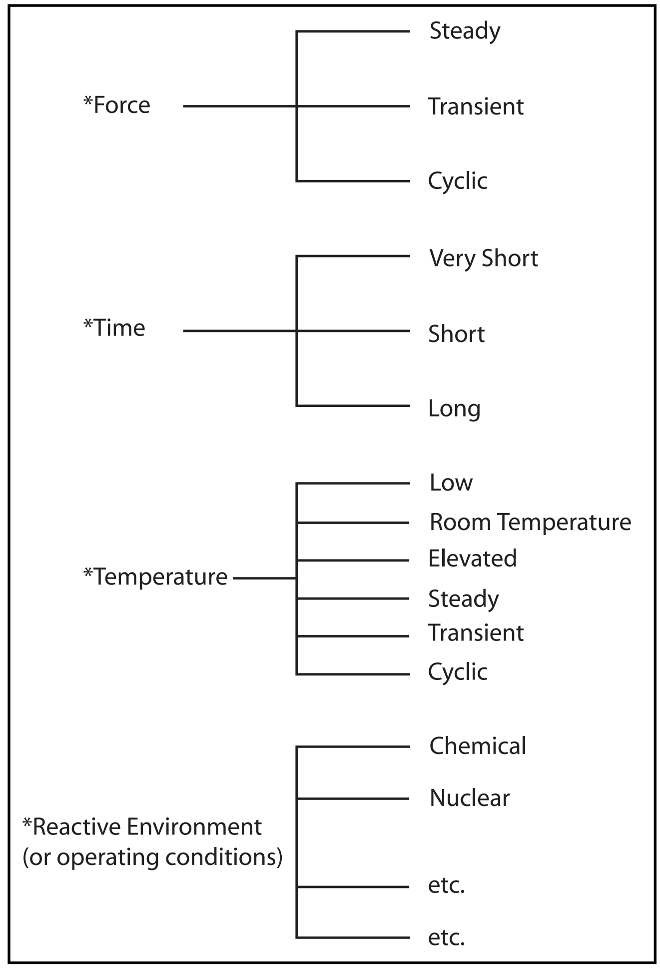


Table 1. The Process of Analytical Troubleshooting

Frequently, when a machine stoppage or failure occurs, the organization fails to correct the problem because:

1. Incomplete information was provided as to the description of the problem.
2. The organization has incomplete knowledge about how the machine is supposed to work in the first place.
3. The maintenance department attempts to correct the problem based on someone's assumption as to the cause of the problem.
4. The maintenance department corrects symptoms of the problem instead of locating and eliminating the true cause of the problem.

These trouble shooting shortcomings must be overcome, if effective problem-solving and failure analysis is to be done. The following process is a recommended procedure for the initial investigation of equipment problems.

Step 1. Recognize a Problem

A problem is occurring when there is a difference between what should happen and what is actually happening. In order to recognize the difference, one must fully understand how the machine operates. The mechanics, operators, and maintenance persons must have a thorough and complete knowledge of the equipment.

When recognizing a problem, first list all of the symptoms by using your sense of smell, sight, taste, sound and touch. Next, separate and clarify each symptom so that you can consider each condition one at a time. Then set priorities on which symptoms to investigate.

When setting priorities, consider how serious, how urgent and whether the problem is growing.

Step 2. Describe the Problem

Most problems are very poorly described. This frequently leads the maintenance department in the wrong direction and results in inappropriate or incorrect adjustments or repairs being made.

In order to accurately and completely describe a problem there are two considerations:

1. State the problem, using terms everyone can understand, i.e., the air compressor isn't working properly, or one of the new buses has a broken tail light.
2. Specify the problem, by getting all of the facts and write them down, i.e., in our compressor problem, ask what the problem(s) is, ask where the problem(s) is, ask when the problem(s) occurred and ask to what extent the problem is occurring.

The answers you get will vary, depending on how people see the problem. One operator will say, The air pressure gauge is unsteady. Another will tell you, the housing is too hot to touch. A third will say, There's a grinding noise coming from the motor and metal shavings on the floor beneath it.

In our new bus problem, the problem description is extremely poor. It doesn't tell you which bus, nor does it tell you who tail light on the bus is broken. If you respond to this statement without asking what, where, when and to what extent, you may have to inspect 20 buses before you locate the problem! You can see the value of making certain that the "problem is specified.

Step 3. Ask Good Question

There are several ways of questioning to obtain correct information.

1. Open questions prompt people to answer in phrases, sentences or detailed descriptions. Open questions begin with the world what, when, where, who, why, how. Examples of open questions are:
   a. What is the problem?
   b. When did you first notice the problem?
   c. How did the problem start?
   d. What were the conditions in the plant at the time the problem started?

2. Closed questions prompt one word answers and are used to check or expand upon answers to open questions. Closed questions begin with the words do, have, will, are and is. Examples of closed questions are:
   a. Will the machine operate at slow speeds?
   b. Are there other machines with the same problem?
   c. Is the problem confined to one location?

When gathering information, people will frequently tell you what they think you want to hear or they will provide answers based on their own perceived conclusions as to the cause of a problem. In either case, there will be a void in some answers.

In order to overcome this problem, we use a technique called "Questions to the Void." This technique requires us to ask the same questions over and over again using various techniques, in order to get the most specific answer possible.

Examples of questions to the void are; using the phrase, what else, as in what else do you think is wrong with the compressor? Using turn around questions, as in, Why is there a problem with the compressor?

Remember to handle answers effectively. If you do, you will gain and maintain the trust of those people from whom you are expecting answers and information.

After you ask a question:

- Listen to the answer and clarify it, if you do not understand what was meant.
- Acknowledge the answer.
- Confirm what you heard.
- Record the answer. Write it down exactly as you heard it. This will avoid confusion later.
- Do not jump to a conclusion. Remember, you haven't finished your investigation.
- Be respectful to the operator, do not place or imply blame.

Step 4. Investigate All Possible Causes to Locate the Real Problem

In our compressor problem, we have three symptoms (housing too hot, noisy motor, fluctuating air pressure). Remember, these are problem symptoms, not causes.

Write down each symptom and then individually and separately, write down and consider the list of: What could cause each symptom?

Next, test your conclusion; i.e., If one of the causes of the hot housing is a possible lack of oil, but the oil level is correct, you have just eliminated one possible cause of the hot housing.

After testing each possible cause for each of the symptoms, you are left with the conclusion that there is only one cause of the problem that is related to all three symptoms. That is, a partially seized or misaligned bearing which:

- Increases housing temperature,
- Causes fluctuating air pressure, by restricting compressor operation,
- Creates a noisy motor and filings on the floor.

Now you must determine if the partially seized or noisy bearing is on the motor or the compressor. Once determined, you have located the problem. Your ultimate aim will be to determine the root cause of the bearing failure. More on this in the discussion on failure analysis.

When separating and investigating symptoms of a problem, always ask:

- What is different, odd, unusual or distinctive about the problem?
- What has changed in, on, around or about these different conditions?
- How do these conditions affect each other?

Solve Recurring Problems

Recurring Problems are problems which keep coming back. Whether its small or large, a recurring problem happens over and over for one of two reasons:

1. The root cause of the problem was never found, or
2. The action taken to fix the problem wasn't complete or permanent.

Unfortunately, people tend to accept recurring problems as normal. They tend to work around them instead of solving them--probably because recurring problems seem hard to solve. The truth is recurring problems can be as easy to solve as any other type of problem. That's because whenever a recurring problem starts, there has to be a change in operation, and whenever the problem stops, there also has to be a change in operation.

These changes will almost always lead you to the cause of the problem. If you put the skills and techniques that have just been outlined to work for you, you will become an excellent maintenance trouble shooter. You can become an even more effective trouble shooter if you adopt one simple rule: The best time to deal with problems is before they occur.

There are four steps to success in the prevention of problems before they occur.

1. Identify potential problems. (Get into the habit of looking for trouble.)
2. Identify the likely causes of these potential problems and always record them.
3. Establish preventive and predictive techniques to prevent or predict problems.
4. Plan contingent action and preventive/predictive maintenance task triggers in order to establish the proper intervals for appropriate action.

The W5H Trouble Shooting Process

The W5H questionnaire can be attached to (or become part of) the tradesman's work order whenever troubleshooting is required to determine a problem and may also be used to gather the initial information before beginning the root cause analysis process. The W5H questions would be primarily aimed at operators or production personnel.

WHAT – Is the problem?
WHERE– Did the problem occur?
WHEN – Did the problem occur?
WHO – Was present when the problem occurred?
WHY– Do you think the problem occurred?
HOW - Do you think the problem can be eliminated?

Maintenance RCFA 5Y Form

The 5Y form is another document that may be used to troubleshoot an equipment or process problem by simply asking why until the probable cause is determined.

For example, assume that the Breakdown or Stoppage, is improper hydraulic pump operation. The tradesman/troubleshooter would list the appropriate and "Possible Failure Causes. For example:

- Pump fails to deliver fluid.
- Pump makes excessive noise.
- Pump delivers low or erratic oil flow.

For the most probable Possible Failure Cause, the tradesman would ask why.

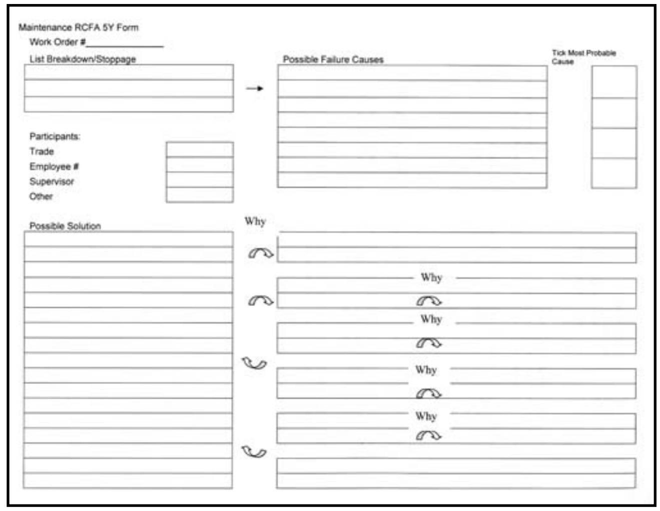
Let's assume that the failure cause is; pump makes excessive noise. The question why might result in several answers, such as; air leaks at the pump intake, clogged suction line, incorrect or cold fluid, worn or broken pump parts, etc.

In turn, the tradesman would ask why for each of these potential causes of a noisy pump, investigate each and ultimately arrive at the right conclusion.

The final step in this process would be to eliminate the cause(s) of the noisy pump and establish preventive and predictive tasks that would prevent recurrence.

Failure Analysis Questionnaire

Failure analysis questionnaires can be attached to, or included with work orders when repairs are being carried out and can be used to gather information about equipment problems at the site of the repair.



Tradesmen and technicians can be trained to think analytically about probable causes of failures and encouraged to investigate failures as machinery components are disassembled for repair or replacement. These failure analysis questionnaires are the first step in the process of root cause analysis.

The first step in the use of the questionnaire is to gather initial information about the failure, such as time, location, operating conditions and how long the machine ran before the failure.

The following questionnaire has been designed to outline ideas and suggestions for carrying out a root cause analysis for a rolling element bearing failure. The format of the questionnaire can be redesigned or rewritten to satisfy the collection of necessary information for any component which has failed.

Please note that when dealing with any failure situation, it is critically important that the analyst be completely and thoroughly familiar with the equipment, the conditions under which the machinery operates and the processes that are used.

Failure to be familiar with these requirements will frequently result in situations where the failure analyst reaches an incorrect conclusion.

Failure Analysis Questionnaire

About the Bearing (or Component Being Analyzed)

► Make and Part Number
► Location and orientation (position) in machine. (Obtain drawings whenever possible).
► Date of installation
► Method of Installation
► Initial Lubrication
grease □ oil □ (Provide a copy of the lubricant type and specification data sheet)
~ (if grease, grade-
oil viscosity-

thickener type-)

~ (if oil, viscosity and EP or Non-EP, etc.)

► How long the component ran prior to failure

► What was the failure progression? (Was there initial noise, heat, etc?)

About the Application

► Speed

► Load

► Duty cycle (i.e., 8 hr. shift, 24 hrs., 7 days per wk., etc.)

► Size and type of other bearings supporting the shaft

► Operating temperatures (at bearing or component being analyzed)

► Operating temperatures (of machine)

► Ambient conditions

(dusty and dirty environment) ☐

(clean environment) ☐

(inside plant) ☐

(outside plant) ☐

► How many previous failures, if any?

► How long between previous failures, if any?

► Have there been any modifications, operating increases, or re-designs made since the bearing (component) installation?

► Present lubrication (Provide a copy of the lubricant type and specification data sheet)

~ Type

~ Relubrication quantity and interval?

~ When was the component last lubricated?

Developing Failure Codes for Root Cause Analysis

When designing work orders or other documents which are intended to gather information about failures or failure causes, it is highly recommended that a section of the work order be devoted to the collection of failure information. This can be as simple as providing a check list of potential reasons for failure. These failure codes include, but are not limited to the following list, with a corresponding reporting format which can be designed in any form and included on the work order as part of the tradesman's report.

Indicate Reason(s) For Failure

1. ☐ Defective Parts	2. ☐ Fire
3. ☐ Overload	4. ☐ Operation error
5. ☐ Misalign/balance	6. ☐ Dirt/dust
7. ☐ Fatigue	8. ☐ Improper lubrication
9. ☐ Misuse	10. ☐ Not failure related
11. ☐ Corrosion	12. ☐ Improper inst./repair
13. ☐ Overheat	14. ☐ Process fluid leakage
15. ☐ Turbulence	16. ☐ Aeration
17. ☐ Oil leakage	18. ☐ Improper component
19. ☐ Wrong seal/O-ring material	20. ☐ Cavitation
21. ☐ Incorrect design	22. ☐ Excessive electrical resistance
23. ☐ Expansion/contraction	24. ☐ Restricted flow
25. ☐ Low/no pressure	26. ☐ Improperly adjusted mechanical seals
27. ☐ Poor breather systems	28. ☐ Oxidation
29. ☐ Improper pressure settings	30. ☐ Poor quality/incorrect filters
31. ☐ Other (specify)	

Summary

The process of root cause failure analysis should consist of the following seven steps.

1. Clarify the problem. Ensure that you are responding to a real problem and not a symptom.
2. Review the history of the applicable conditions, machinery, or processes that might have contributed to the problem.
3. What has changed? List every condition potentially related to the problem.
4. Evaluate equipment, materials, methods, processes, as well as external conditions, such as time of day, weather, temperatures, recent power failures, etc. Again, what has changed? One very useful technique is to set up a video camera to record machine or process problems. The camera can be retrieved and the video studied to analyze potential problems which in turn contribute to a machine or component failure.
5. Plan the investigation.
   - Which part caused the failure?
   - What? Why? When? Where? Who? How?
   - Did lubrication problems cause the failure?
   - Did operating conditions change?
   - Have there been modifications to the machine?
   - What was the last thing done to the machine?
   - Have there been changes to the process used?
   - Could preventive maintenance have prevented the failure?
   - Could predictive maintenance used to monitor the condition have predicted the failure?
   - Did human error contribute to the failure?
   - Is training or retraining required?
   - How can a recurrence be prevented?
6. Investigate all possible causes and malfunctions using technologies which might shed light on the root cause of a failure, such as ferrographic oil analysis reports which might confirm contamination, wear, or other conditions that may have contributed to the failure.

   Review vibration analysis data, or applicable thermographic imaging to determine if imbalance, misalignment or temperature conditions may have contributed to the failure.

   Have component parts analyzed using scanning electron microscopy (SEM), or appropriate non-destructive testing techniques, such as magnetic particle, liquid penetrant or eddy current evaluation carried out to determine the root cause of the failure.
7. Formulate improvement plans, carry them out and monitor and evaluate results for success.

Above all, remember that approximately 50% of all maintenance activities in North America result from our apparent willingness to continually accept reaction to catastrophic equipment failures. If we just put down the fire hoses long enough to prevent or predict these occurrences, our reliability would increase and our costs would decrease by some 30 – 40% respectively.

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Managing Electrical Reliability through CBM

By Roy Huff, Snell Infrared

Is calling your local thermographer for your annual electrical survey considered a predictive maintenance program at your plant? If it is, you may be missing the opportunity to achieve Electrical Asset Reliability through Condition Based Monitoring (CBM). Here are just a few of the questions you should be asking yourself: Am I inspecting the right equipment at the correct frequency? Is my thermographer qualified and is he providing useful recommendations in a quality report? What other technologies should I be incorporating in my program? Electrical Ultrasound? Motor Circuit Analysis (MCA)? Power Quality? Grounding Surveys? Are the testing results being integrated between these technologies and other CBM technologies?

In-house, Subcontract, or Hybrid CBM Programs

Each of these approaches toward a CBM program has advantages and disadvantages. You may feel that you don't have the flexibility or ownership you want or need if you subcontract. Re-qualification or reassessment of repairs has to be scheduled. Report formats may not be flexible. Buy-in at the skilled trade level of the program, results of the inspections and repair recommendations require constant support and promotion.

Internalizing the CBM program has its challenges as well. Selection of personnel and testing equipment is critical to the success of in-house programs. Training and qualification or possibly certification of the technician(s) requires time and money. The possibility of that technician leaving or retiring starts that process all over again. Is your facility large enough to support a full time thermographer(s) or motor circuit analyst or will periodic inspections just be one of their many responsibilities?

One very effective method of getting up to speed quickly can be to work with a contractor to establish an infrared program or CBM program that may be internalized with their support, training and development over time.

Scope of Work

If you have had infrared inspections or motor testing completed in the past you may know exactly what you want to include in the program. If you are new to CBM technologies and you are willing to look past the "old standard" annual electrical inspection, your contractor should be able to offer ideas and applications that could greatly increase your return on investment. Do you need an electrical or an electrical/mechanical infrared inspection? Are there processing and manufacturing applications? Could you benefit from a trending program or a roof moisture survey? Should the warehouse motors be tested? These are questions your contractor should be able to help you with.

Is this a one-time inspection, a continuing routine inspection or the beginning of a CBM program that could offer a turnkey package in a few years? If your plan is the development of a CBM program, you want to be sure your contractor can support these activities. The contractor should be able to walk down and evaluate the site assets to determine what equipment can be tested. From this asset list, inspection routes and frequencies can be determined based on quartile coverage and asset criticality. Quartile coverage is based on industry vertices and criticality should be based on the results of an asset criticality assessment. Inspection of all or most electrical systems and critical mechanical equipment should be the primary focus of the initial infrared inspection. Critical motors, transformers, and generators should receive MCA testing on a periodic schedule.

The contractor should also have the capability to develop inspection and testing procedures for special applications. This may include manufacturing processes and roof moisture surveys for infrared and DC motors, transformers and generators for MCA. As the CBM program matures, your site may determine it is time to buy equipment and conduct you own inspections. The contractor should be able to support these efforts by suggesting approved infrared and MCA training and supporting mentoring sessions, develop an American Society of Nondestructive Testing – ASNT based infrared program, and provide or suggest a source for ASNT Level III services by an ASNT NDT Level III certificate holder or company. MCA does not currently have a recognized certification process.

Identifying Contractors

This may be as simple as taking a walk through the yellow pages. The World Wide Web can also be helpful in identifying potential companies. In addition, meetings and conferences may provide an opportunity to ask others who they use or might recommend. Call your friendly CBM Training Specialist. Chances are they have trained an infrared thermographer or MCA technician near you or can direct you to someone with experience in your unique applications.

The contractor should have someone on staff responsible for their CBM offering. These responsibilities can be met by someone having the appropriate experience and training or by obtaining the services of an outside agency to act as their ASNT NDT or PdM Level III certificate holder. This person or company should be responsible for developing inspection procedures, providing certification training and testing for contractor technicians and the appropriate participating onsite personnel, along with overall project management for the CBM program.

A Written Practice describing the contractors qualification program, including their certification training, experience and testing requirements, should be on file. These requirements must meet or exceed ASNT SNT TC-1A guidelines. Inspection procedures should be established for all standard applications and the contractor should have the ability to develop inspection procedures for any unique infrared applications. The contractor should provide three industrial references and have general liability insurance in effect for the entire contract period.

The Technician (Is he qualified?)

The thermographer should fulfill the requirements needed to meet ASNT Level I or Level II certification. These requirements are described as follows. The technician must have attended and passed a Level I and/or Level II training course that meets the educational requirements of ASNT TC-1A. The thermographer should have passed an ASNT recognized Level I and/or Level II certification exam, each consisting of two written exams and a practical exam, in accordance with ASNT TC-1A. The thermographer should have a minimum of one year of full time thermography experience. The thermographer will be responsible for conducting the inspection, interpreting the images and creating the report. Therefore, he must be thoroughly familiar with performing a wide range of thermographic inspections and must fully understand both the parameters to acquire accurate temperature measurements and how to utilize the data when analyzing it. Whether you need a Level I or Level II thermographer will depend on the contractor's infrared program and its inspection procedures. By definition, Level I thermographers are qualified to perform specific inspections, specific evaluations for acceptance or rejection according to written procedures. Level II thermographers, in addition to Level I capabilities, are qualified to interpret and evaluate results with respect to applicable codes, standards and specifications. Many insurance companies require inspection work be completed by a Level II thermographer for the insurer to receive any discounts or credits. Although MCA does not have a recognized certification process, the one outlined for thermography makes a good outline for this technology.

Equipment and Reporting

Many times your applications will drive the decision on equipment selection. Other times the budget may decide. With the latest evolution of infrared equipment, image spatial resolution improved dramatically and also has portability. If image quality is important to you, you may want your contractor using a Focal Plain Array imaging system. If temperature measurement is a valuable asset to your inspection data, you will want the contractor equipment to be fully radiometric. If a tour of your plant involves steps, ladders, equipment on all different levels and narrow passages, you will want his equipment to be handheld or very portable. If you plan to archive data and images for trending or records, cameras with digital storage capability will support that need. Many infrared thermograms or images need the support of a visual image to correlate components and locations, so ask your thermographer if he will be taking visual digital photos. MCA testing is a relatively new technology. Both online and offline capabilities exist. Online, offline or a combination of these capabilities may be needed, depending on your needs and applications.

Ask to see a sample report. Your contractor should be prepared to edit the report template to meet your needs. If there are details not included in the report form that you need, ask for them. Determine the report format and how many copies you want up front. There may be a charge for extra copies. Will it be printed and bound? Will it be delivered on CD or emailed? Will it be web accessible with the technologies integrated? When will it be completed? Who owns the data? These are all questions you should ask the contractor to avoid any misunderstandings.

What Can You do to Help?

After an exhaustive search you have chosen a CBM inspection company. What can you do to prepare for the first visit? If you can provide a complete list of plant electrical assets and a list of rotating assets, from this information a 100% theoretical asset health matrix can be generated and appropriate CBM technologies can be applied. The level of coverage will need to be discussed and agreed upon based on desired quartile coverage and asset criticality. With the exception of offline MCA testing, equipment that is offline cannot be inspected. Have as much equipment online as possible or make arrangements to cycle equipment that is used periodically. Make sure the plant is aware that an infrared inspection or MCA testing will be taking place. Obtain camera property passes for the visual digital camera and the infrared camera if necessary. You will be asked to provide qualified escorts for the technicians. Make sure the escorts you provide are qualified to open and remove electrical panels, make and break electrical connections, operate equipment, have the proper tools for this project and understand all safety procedures. Notify the contractor of any special safety equipment needed, especially if your company does not provide it. If any liability insurance documents are needed prior to the contractor starting the inspection, make sure he is aware of this and can bring these documents with him or fax them prior to his arrival. Should the viewing of a safety film be required before the contractor can start work, make sure those arrangements are made. It may also be helpful to provide the contractor with operating hours and hours of peak loading. If utility owned equipment is to be inspected, contact you local utility to arrange for the opening of transformers, etc. Taking these steps will smooth many potential delays and start the inspection off on the right foot.

CONCLUSION

Electrical asset reliability is part of asset reliability. There is no "silver bullet," no one technology that is going to deliver asset reliability. Instead, a successful CBM program starts with the application of the appropriate electrical and mechanical reliability technologies on the right assets with the correct frequency. Integrating the results of those technologies, to support repair recommendation and generate prioritized work orders that are planned and scheduled is the next step. Having a well-trained skilled trade workforce to complete these repairs will provide a facility the opportunity to enjoy the benefits and profits provided by having reliable assets.

Improve your Maintenance Management Skills with RCM

By Douglas Plucknette and Terry Harris

As a maintenance manager you are often held accountable for the operations of all the processes and equipment functions at a facility. Your actions are visible to everyone on a day to day basis. The success you have with your responsibility usually determines your career growth. Your success depends on how well you eliminate problems, improve and maintain uptime and process functionality.

As maintenance managers we sometimes wish we could find the crystal ball that we gaze into and see future equipment failures. How easy that would make it to be ready with equipment and resources to get things fixed and back in operation. There are all the predictive technologies available that give us this crystal ball effect to let us know when components will be failing long before the failure occurs. We spend thousands of dollars each month and year to use the predictive technologies, but are we doing the right thing?

I have worked at and with many companies that have bought into the predictive technology programs. I train and consult companies on how these technologies work and try to keep up with all the advances this field is making. I have also lived the routine of hap hazardly using these technologies or just to cover all my bases I just used all the technologies on every piece of equipment. Great method but not very cost effective. How about the budget in your PDM line item going from $2,000 per month to $20,000 per month? That will raise an eyebrow on a budget review, better not be having any downtime when you explain your theory!

There is a successful process that can be used to determine exactly what we should be doing on every component in our equipment. This process has been used successfully in the airline industry, Nuclear power plant industry, military, and many other manufacturers. It is the RCM analysis process. This process allows us to determine the correct maintenance to perform on every component in our equipment.

So what does RCM do that can make it such a great tool? First it helps us look at the equipment that needs maintenance and the equipment that does not. You may be thinking now, what equipment doesn't needs maintenance. If you have two valves in your plant, one serves as cooling water control to your process and the other supplies water pressure control for the automatic lawn sprinkler system, do we apply the same resources? If we do we are wasting resources on the lawn sprinkler valve. It could be run to failure and then replaced.

If we have two fan systems that are supplying fresh filtered air to a process. One fan system has two fans with 50% capacity each and the other has two fan systems that have the capacity of 100% each, which one should get the most resources. It's the one with 50% capacity each. If one fails your process looses functionality. If one of the 100% capacity fans fails you still maintain process functionality. The RCM process is used by aircraft manufacturers to determine what maintenance should be performed on each component. While most people recognize the success RCM has brought to the airline industry in developing a complete maintenance strategy, few take time to understand how the process would apply to there equipment and careers.

When you watch your plane pull up to the gate, while you are waiting on your flight, you don't see 10 maintenance people run out to the plane and start greasing and lubing. They don't take parts off on put new parts on. If you see this happening you may want to get another flight! This is not normal procedure and the proper testing will not be completed at the gate. The rebuilds are time or cycles based and determined through testing and failure rates. Parts are replaced before they fail but for a reason. The 50-400 passengers that will be on the flight are the reasons. The consequence of failure is high. They are not changed because that's the way we always did it in the past.

So why is this process so important to your successful career? Why can it make a difference? Let's look at some RCM fundamentals and see if any of them make you think differently about how you perform your role.

1. RCM will help you see that you are trying to maintain system function and not equipment function. The process of performing an RCM analysis will let you see that some components in the process do not require specific maintenance. Some components are more important in maintaining process function than others. These are the ones that we concentrate our efforts and resources too for the most efficient cost control.
2. RCM defines loss of function as not just being down and total loss of function. It defines loss of function in the areas of quality. We are all in business to produce quality products or guess what happens, we are not in business! It defines loss of function in the area of reduced production. Yes, we are still operating but at a reduced rate, so our competitors are making the product we should be making. It defines loss of function in the areas of Health, Safety, and Environment. We are operating but we have a loss of function and are creating safety issues, health issues, or environmental discharges. RCM looks at all these areas as loss of functional capability to what we are supposed to be doing each and every day.
3. The process of RCM helps us identify all possible failure modes of each component in a process. You will discover with the knowledge of your RCM team, failure modes you may not know existed. You will address failure modes that are likely to occur. Once these failure modes are identified you can select tasks that will predict the failure will occur, prevent the failure from occurring, eliminate the failure, or reduce the consequences should the failure occur. RCM Blitz will direct us to tasks to get the results and its part of its structured database.
4. The RCM process will help you define written procedures. As perform the RCM process you will realize that you need to modify written procedures to better eliminate or prevent failures. I have found many companies do not have detailed written procedures for maintenance or operations. I often hear the phrase, "written procedures, my operators or maintenance people have been doing their jobs for 20 years, why do I need a written procedure?" RCM identifies where procedures may be lacking or need written or revised.

What if we can't predict, prevent, or eliminate the failure from occurring, then where do we go? What is left for us to do with a component or piece equipment that falls into this category? With RCM blitz we go to what is called the Consequence Reduction Strategy. We will develop procedures to get the component or piece of equipment back into service quickly. Having spare parts on hand, having written procedures to reduce repair time, and establishing training programs on the component repair.

So looking at RCM as a tool to help you be a better maintenance manager, why would anyone take the risk with their career? It's the ultimate tool to prepare you to the next best thing to the crystal ball. RCM is a proactive tool that can make you a better maintenance manager. Your career may depend on it; your advancement from this position is much better by being proactive.

If we look at all the failures that can happen with our equipment and processes, what should we do? We can wait and develop procedures and plans as components fail. We can perform predictive technologies on everything or some things that don't need them. We can perform the wrong inspections with the wrong equipment. Or we can do as John R. Chute states. "Let's do the right maintenance at the right time on the right equipment"

There are training programs available on RCM Blitz that can take you to this level and help advance your career. Don't take the chance.

A Maintenance Planning and Scheduling Case Study

By R.D. (Doc) Palmer, PE, MBA, CMRP

INTRODUCTION

This paper presents the turning around of a mechanical maintenance planning department. It explains how planning leverages maintenance productivity and how its effect is quantified. The specific principles necessary to make planning and scheduling effective are presented and the issues underlying each principle are identified.

This work was done in the early 1990s at the largest station of one of the largest municipal electric utilities in the United States where the author was (and still is) an engineer within the maintenance department. Even as the planning program was being addressed, the utility already had a superior maintenance record. The utility had achieved a yearly equivalent availability factor (EAF[1]) from 1990 to 1994 of 91%, 86%, 90%, and 90% for its steam generating units, well above industry average. The EAF calculation included all derations and outages including overhauls.

A multi-faceted maintenance management improvement effort insured continued maintenance effectiveness. This effort comprised areas such as communication and teamwork, storerooms, rotating spares, tools, tool rooms, shop improvements, training at all levels, equipment database and CMMS, PM, PdM, project work, and improvements to work processes. Many of these areas were mature and already contributing to the utility's success. The most recent area to come into its own was planning and scheduling.

Company Vision and Planning Mission

Of course in one respect, a company should not want to do maintenance. Gifford Brown, Manager, Cleveland Engine Plants, Ford Motor Company, says it best:

"The company vision should be how to PREVENT maintenance, NOT how to do it efficiently."[2]

However, knowing that some maintenance is necessary, work order planning was considered an important tool. Some of the primary aspects of planning were well known. Work order planning involved identifying parts and tools necessary for jobs and reserving or even staging them as appropriate. As more was learned about planning, it became apparent that planning was also a system with many subtleties.

"Having the right jobs ready to go" sums up the planning mission statement. Having the "right jobs" involves job priorities, crew schedules, and work type (such as PM versus breakdown work). Having the jobs "ready to go" involves correctly identifying the work scope, considering the safety aspects of the job, and planning to reduce anticipated delays such as for instructions, parts, tools, clearances, and other arrangements.

The practical result of implementing planning for the station's mechanical maintenance department was 30 maintenance persons yielding the effect of 47 persons.

At this point, it must be stated that the benefits of planning involve quality as well as productivity. It is very dangerous to push for productivity if there is not a quality focus present in the work place. Craft persons must have the attitude that work being done in a quality fashion is more important than meeting a production schedule. The individual on the floor must communicate concerns with the crew supervisor if more time is needed to complete work properly. Tangible quality savings come from improved availability, boiler heat rate, and safety in two ways. First, planning focuses on correctly identifying work scopes and provides for proper instructions, tools and parts being used, thereby facilitating quality work. Second, productivity improvement frees up craft, supervision, and management time to do more proactive work. This proactive work includes root cause analyses on repair jobs, project work to improve less reliable equipment, and attention to preventive maintenance and predictive maintenance.

The reduction of delays is where planning impacts productivity. The majority of the maintenance budget is typically wages and benefits. Studies during the last four years of high availability indicated that productivity of available maintenance persons was about 35%. That is, on the average, a typical maintenance person on a 10 hour shift was only making productive job progress for 3 1/2 hours. The other 6 1/2 hours were spent on "non-productive" activities such as necessary break time or undesirable job delays to get parts, instructions, or tools. 30 to 35% productivity was typical of traditional-type maintenance organizations. Yet it was clear that the significant overall cost of maintenance and the average of 6 1/2 hours "non-productive" time per person were opportunities to improve maintenance efficiency. Simply implementing a fundamental planning and scheduling system should help improve productivity from the 30 to 35% of a traditional type maintenance organization to about 45%. Then as files become developed to allow avoiding the problems of past jobs, productivity should increase to 50%. Finally, a good CMMS should boost productivity to over 55%.

Taking technicians out of the work force to make them planners makes sense because a single planner can plan for 20 to 30 persons. This ratio is well above the break-even point. If a planner could help multiply the productivity of a single technician by 57% (55% divided by 35%), the break-even point would be taking one of every three technicians and converting them to planners:

Without Planner:	3 persons at 35% each = 3 X 35% = 105% total productivity.
With Planner:	2 persons at 55% and 1 planner at 0% = (2 X 55%) + (1 X 0%) = 110% total productivity.

The 30 person maintenance force is leveraged as 30 persons X 1.57 to yield a 47 person effective work force.

The Six Principles of Planning

Six principles were determined necessary to make planning effective.

Principle Number 1

The first principle is to have a separate department. There is frequently significant pressure on the maintenance supervisor to get repairs completed. It is tempting to reassign a planner to a toolbox, saying, “One of those planners is a welder, he can come help us.” This situation is avoided by removing the planners from direct control of the maintenance crew. The reason they need to be separate is they need to focus on future work.

Principle Number 2

A simple definition of future work is: the crew has not yet been assigned to start on the work order. Once a crew has started working on a job and they find out they need more parts information, they do not come to the planner for assistance. If the planner is constantly helping technicians find file information for jobs-in-progress, the planner has no time to file or retrieve job information to help future work and a vicious cycle is in place. A planner must be able to find those last three work orders from the last four years to help the crew avoid previous problems. For example, if the planner finds that the last time the crew worked this job they did not have a certain part, the planner makes sure they have that part this time. The job is on a learning curve. Looking to the files helps get that improvement opportunity. That lets the planner focus on getting all of the work planned in advance. In addition, if a planner can tabulate the previous cost, better repair or replace decisions can be made. This arrangement is also necessary for the crew supervisors to maintain their familiarity with the files and encourages feedback from the technicians. Once a technician has to find technical information for a job, feedback to the files is encouraged if he knows that otherwise, the next time he works the job he will have to find the information again himself.

Principle Number 3

Once the planner gets job feedback for future reference, it cannot go into a system level file. A system might have 20 to 100 components with many work orders. When a file is that large, information cannot easily be found on a single piece of equipment. So planners use a component level file for each piece of equipment. When a work order is received, the planner consults the specific file to find the previous work orders for that equipment. These component files used were simple paper files.

Principle Number 4

It would seem that with the feedback and file system in place, clerks might be utilized as planners. However, as a minimum, planners need to be skilled technicians so that they can intelligently scope a job or inspect the information in a file for its applicability to the current job being planned. One issue at stake is in whether to have (hopefully) good execution on an excellent job scope or have excellent execution of perhaps the wrong job scope. The JEA feels that identifying the correct job scope is of primary importance. Another issue is the development of time estimates. The opinion of the skilled technician-planner is preferred over strict file information, pigeon holing, and other built up time estimates. The planner estimates how long it should take a good technician without unanticipated delays. Planners must also have a high degree of self-initiative.

Principle Number 5

Planners have to be careful not to put so much detail in a plan that they cannot plan all the work. A general strategy for 80% of the work hours is preferred over a detailed plan for only 20%. Therefore the planners must respect the skill of the craft. Supervisors must shore up technicians with deficient skills rather than the planners planning jobs for a lower skill level. In the past, the planners had not only wasted time planning unnecessary details, but had affronted skilled technicians. On the other hand, if there is a procedure already in the file or if the persons who previously worked on the equipment reported helpful feedback, the planner would include those items in the package. The planner should also include information as to why the certain job strategy was chosen, especially when the file history helped make the decision. For example, "This valve is being replaced since patching it in the past has not worked well" (the planner knows the file history).

Principle Number 6

Finally, work sampling (also known as wrench time) gives the measure of whether planning is helping. At issue is not so much the time the technician spends doing productive work. What is truly important is the analysis of the non-productive time. For example, how much time is spent waiting for parts? Wrench time is properly measured with a statistical study. Separate studies done over time indicate if planning is getting better or worse.

Scheduling

After these principles had been incorporated, a work sampling study was done. Comparisons to earlier studies indicated that some delay areas had been reduced. But it appeared that overall productive time did not increase because more work had not been assigned. Advance scheduling was therefore considered necessary for improvement.

The basics of scheduling revolve around giving enough work to the crews to fill up the crews' forecasts of work hours available. Again, six principles were determined necessary to make scheduling effective in getting more work completed.

Schedule Principle Number 1

The essential part of Principle Number 1 is that jobs must be planned to identify skills and hours needed. Plans also identify the lowest skill necessary to complete the work. By identifying the lowest skill necessary, the crew supervisor has more latitude later when determining which individuals could execute each job plan.

Schedule Principle Number 2

The importance of schedules and job priorities cannot be presumed. Advance scheduling enough work for an entire week sets goals for maximum utilization of available craft hours. It helps insure that a sufficient amount of work is assigned. While planning reduces delays during jobs, scheduling reduces delays between jobs. Advance scheduling also helps insure that sufficient proactive work to prevent breakdowns is scheduled along with reactive work. It also allows more time to coordinate resources for completing work such as intercraft notification and staging of parts. In addition, the plant must always watch over the process of setting proper priorities on work. If everyone assigned a high priority to their work just to insure its completion, then improperly prioritized jobs would delay true high priority jobs (directly affecting plant availability). They would also make it hard to recognize true instances of when the advance schedule should be interrupted.

Schedule Principle Number 3

The actual schedule is a one week schedule made from a forecast of the highest skills available. From knowing the highest skills available, the scheduler has more latitude when determining which job plans could be executed the next week. Another point is that advance scheduling is really more of an allocation of work to be done and not a detailed schedule of exact individuals and time slots.

Schedule Principle Number 4

Principle Number 4 brings the previous schedule principles together. The main part of this principle is that the scheduler assigns work plans to be executed during the following week for 100% of the forecasted hours. Over-assigning and under-assigning work each cause unique problems that can be avoided. For example, assigning work for 120% of forecasted work hours may seem to be a way to provide enough work for the crew in case some of their jobs could not be cleared. It would also seem to encourage the crew to stay busy. But it then becomes difficult to gauge the performance of a crew when trying to compare what they did accomplish to what they should have been able to do. It certainly lacks a motivating appeal to ask why a crew only accomplished 110 hours worth of work with the 100 work hours it had available. Also coordination with plant operators and other crafts may be more difficult if there is less confidence that equipment will be worked on. In the other situation, assigning work for only 80% of forecasted work hours may seem to be the way to handle emergencies or high priority work that may come up. In this case it is also difficult to gauge performance and it would be difficult to ask a crew to improve if it did all of its assigned work. In reality, assigning work hours for 100% of forecasted work hours nearly always inherently includes some jobs that can be easily interrupted in case emergencies arise.

Schedule Principle Number 5

Once the week has begun, obviously some jobs will run over and some will run under their planned work hours. That is one reason that daily scheduling is best done by the crew leader who is close to the field situation of job progress. Equally important is the ability of the crew supervisor to assign particular jobs to individuals based on their experience or even their need to learn.

Schedule Principle Number 6

Finally, while wrench time is the best measure of scheduling performance, schedule compliance is also tracked. It is expedient to measure schedule compliance in a way to give the crew the benefit of any doubt. Consider a crew given 10 jobs and the crew started all 10, but only completed 9. The crew would be 100% schedule compliant rather than 90%. Otherwise, in a second case where a crew received only 1 job and worked it all week without interruption, but did not finish, one would be reluctant to grade them as 0% schedule compliant. Again, the crew is rated as 100% schedule compliant. In actual practice, the situation is as follows: the work hours delivered to the crew are tracked for the following week's work (say 1000 work hours). Then at the end of the week the crew returns all work they did not start (say 100 work hours). The schedule compliance is very easy to measure: (1000 - 100)/1000 times 100% = 90%. (That the crew may have only actually completed 850 work hours is not a problem as long as overall forecast claims for available and carryover hours the next week are monitored.)

Proactive Work

The last barrier to having an effective system was removed with the recognition of the existing maintenance culture. John E. Day, Jr. PE, Manager at Alumax of South Carolina has done excellent work dealing with this factor. He points out that the standard definitions of maintenance are along these lines:

Repair	To RESTORE by replacing a part or putting together what is torn or broken: FIX, REJUVENATE, etc.
Maintenance	The act of maintaining. To keep in an existing state: PRESERVE from failure or decline, PROTECT, etc.

He explains, “The key paradigm is that the maintenance PRODUCT is CAPACITY. Maintenance does NOT produce a service.”[3]

Initial disenchantment in implementing the planning system at JEA was primarily due to an attempt to provide detailed work plans on reactive jobs. Since reactive jobs by their nature are urgent, it is frustrating to everyone to wait on a planning group to turn over the work. And JEA was having difficulty planning all the work. Planning became successful when it reduced research on reactive work. Reactive work still received planning before crew assignment, but the planners began to rely more on the technicians in the field researching a job if there was no file information. Not only did this methodology allow all the work to be planned to allow scheduling, but it reinforced planning Principle Number 2 for feedback.

The challenge is to continue to keep planning and scheduling proactive work while a significant amount of reactive work orders is still being written. The JEA is now further developing its PM program to have a three week backlog of work with equipment not breaking.

Results

The start of weekly scheduling began in the middle of May 1994. The amount of work orders being completed for mechanical maintenance went from about 150 per month to over 250 per month in June and July. So much work was done that even in mid-June there started to be insufficient backlog to schedule for the entire amount of work hours available for each crew. The reason was that the crews had worked down their entire outstanding backlogs. These backlogs had even included some work orders that were over several years old. (At this point, it was decided not to do a work sampling study since the crews had insufficient work backlogs for maximum productivity.) With the station's units caught up in backlog, personnel were available to assist other stations. The station was also able to proceed into its fall 1994 major overhaul of its largest unit successfully with virtually no contract labor.

Present and Ongoing

Emerging from that unit's overhaul, the utility included the electrical and I&C crafts (except for the controls maintenance) as well as two other stations into the planning system. The total of the maintenance force at this point was 137 persons. With a 57% productivity improvement from planning and scheduling assistance, the utility expected to free up, in effect, 78 technicians. These technicians would be available for work to:

- Do outage/project/contractor work.
- Modify existing units.
- Build and maintain new units.
- Insource.
- Do maintenance for others.

References

1. EAF is a common utility performance measure of how much generating capacity is actually available over a given period for producing power.

2. Society for Maintenance and Reliability Professionals Annual Conference, October, 1993.

3. Society for Maintenance and Reliability Professionals Annual Conference, October, 1993.

Procedure-Based Maintenance

By Jack R. Nicholas, Jr. (P.E., CMRP), MQS LLC and Drew D. Troyer (CRE, CMRP), Noria Corporation

Abstract

This paper introduces a compelling argument for development of and adherence to procedure based maintenance when implementing and executing a modern program to ensure maximum capacity of a plant and reliability of its equipment. The argument is based on a new analysis of four statistically significant failure profile distribution studies over the period of the last 40 years, the latest of which was completed in 2001. While all of the studies involve failure profiles in mobile platforms (two for commercial aircraft, and one each for surface warships and nuclear powered attack submarines) the conclusions that can be drawn from them apply equally to fixed facilities, commercial transportation systems and utility infrastructures of all types. Several case studies are included to emphasize how these findings cross over to manufacturing, utility, and government equipment and systems.

INTRODUCTION

In the field of maintenance the traditional approach has been to rely upon the intuitive knowledge and skill of the crafts-persons who conduct it. There is a great deal of pride of workmanship and, in all too many organizations, a great deal of psychic income, as well as significant overtime pay, is tied to failure – more specifically the successful completions of emergency repairs required to return equipment to operation after unplanned shutdowns. There is a mystique that accompanies all of this and there is often perception among skilled craftspeople and management the many variables in associated with the art of equipment maintenance renders compliance with written procedures impossible and impractical. At its best, tribal knowledge dictates how maintenance e gets done. At its worst, chaos rules the day. This is a sage approach to maintenance whereby the attitude "it's the way we've always done it" prevails and that "way" is assumed to be the best and only way to conduct corrective maintenance. With this approach, the consistency with which tasks are completed varies dramatically from craftsperson to craftsperson and, in particular, from site-to-site within an organization. At an individual level, the sage, or tribal knowledge, method of passing information from one generation of craft employee to the next is unreliable, which results in trial-and-error approach to training, which is costly and contributes further to inconsistency in the completion of tasks from one generation of craftsperson to the next. For the multi-plant organization, the sage approach to managing maintenance knowledge compromises the organization's ability to benefit from scale economies associated with the application of best practices across multiple sites.

This problem spills over into preventive maintenance too, resulting in the belief that the craftsperson's own intuitive knowledge is preferable to a written procedure and/or a thoroughly defined checklist. Aside from these problems, most organizations have allocated no resources to creation and on-going support of procedures and checklists. This is, at best, a lost opportunity for increased profits from existing assets and at worst a fatal management omission.

Compounding matters, organizations in the world's most industrialized countries are about to face a major loss of this loosely held knowledge in the form of retirements as our baby boomers, who represent the majority of our industrial craftspeople, beginning in about 2008 and continuing at a rapid pace until 2020. We're at-risk of losing our experience-based knowledge and heuristics for maintaining equipment at a rapid pace, a phenomenon called corporate amnesia. And, the younger generations of prospective craftspeople were much more likely to grow up playing video games and working on computers rather than tinkering with cars and motorcycles (the ever increasing complexity of vehicles has contributed to this phenomenon), so the core understanding of how machines operate one used to learn from experience (and helping dad, of course!) has been replaced with knowledge about how computers and computer software operate.

Lost in all of this is the concept of ensuring and sustaining reliability as both corrective and preventive maintenance is performed. Ideas about how things fail that we used to rely upon as a basis for preventive maintenance have been shown in the four failure profile studies over the past 40 years to apply to only a minor percentage of failures. From this it can be shown that time directed maintenance also should apply to only a minor portion of the failure modes which an organization must correct or mitigate. Further it can be shown that intrusive, time directed maintenance can be detrimental to reliability. Non-intrusive maintenance and monitoring tasks should be sought, instead. Indeed, because of the distribution of the failure profiles described in this paper, the only logical approach for the mitigating failures in the majority of equipment is through the use of non-intrusive procedures.

As modern condition-based maintenance tools and analysis methods come into use, most of which are non-intrusive, the requirement for procedure based maintenance becomes even more important. Analysis of data from modern tools such as vibration monitoring, lubricant and wear particle techniques, infra red observations, motor electrical condition monitoring and almost all other technologies depends for accuracy upon knowledge of the operating state of the equipment. Operating conditions and surrounding environmental parameters must be carefully established and recorded in order that thorough analysis can be performed. This can only be established by adherence to carefully written, detailed procedures and checklists. Herein we'll review failure events that poignantly make the case for procedure-based maintenance, followed by a framework for its implementation.

Thresher Disaster - April 10, 1963

One of the earliest revelations of the need for detailed procedures and checklists occurred when the U.S. Navy experienced the loss of USS Thresher (SSN 593) on April 10, 1963. The loss of 129 lives was, to say the least, a very sobering event for the Navy.

Figure 1. USS Thresher (SSN 593), Pictured Above, Now Lies on the Bottom of the Gulf of Maine.[1]

Those familiar with the details of the Thresher tragedy may recall that the investigation board concluded that the ship was lost due to flooding caused, most likely, by failure of a seawater system component that may have been reinstalled improperly during shipyard overhaul. Compounding the casualty were some design flaws that prevented the ballast tanks from being emptied expeditiously enough so as to achieve and sustain positive buoyancy sufficient to carry the ship to the surface in the face of flooding. Internal cooling system designs also featured a lot of piping subjected to submergence pressure, increasing the risk in case of failure. The Navy's response to loss of Thresher was to redesign the flawed systems, back-fitting the changes to all subs in the fleet and requiring these features in all new designs.

A Submarine Safety (SubSafe) program was also instituted as a direct result of the Thresher disaster. From a maintenance standpoint the centerpiece continues to be the requirement that detailed written procedures and checklists be developed and followed to the letter by all personnel engaged in maintenance of specified components of all systems affecting submarine safety. Thereafter, no additional U.S. Navy submarines have even come close to being lost due to a maintenance problem involving the systems included in the SubSafe program.[2]

It was during this decade of the 1960s that the Federal Aviation Agency, aircraft builders and operators came to the revelation (and proved it with statistics) that there was very little relationship between time directed maintenance and (increased) reliability. In fact it can be shown to illustrate the point that time based maintenance can be detrimental to reliability most of the time and that corrective maintenance, done on the basis of skill-of-the-craft and intuition, is the wrong approach for mission, production or safety-critical plant components in any venue.

Those familiar with the origins of Reliability Centered Maintenance may recall the eye-opening conditional probability of failure profile curves. The most well known of these profiles is the bathtub curve, which is characterized by early stage high rate of infant mortality, followed by a flat or constant failure period and ending with rapidly rising wearout stage (Figure 2). It is widely considered, even today by some, to characterize most equipment failures. While the bathtub curve is a useful tool for illustrating the possible and typical probability density functions a machine might produce, statistical analysis shows that for civilian aircraft the bathtub curve applies to the failure pattern for only a small percentage components. Later studies on commercial aircraft from the 1970s, surface warships from the 1980s and then on nuclear powered submarines from the late 1990s into the year 2001 revealed virtually the same finding. The bathtub curve was found to apply to 4%, 3% and 2% in the United Airlines, Broberg, MSP and SUBMEPP studies respectively.[3]

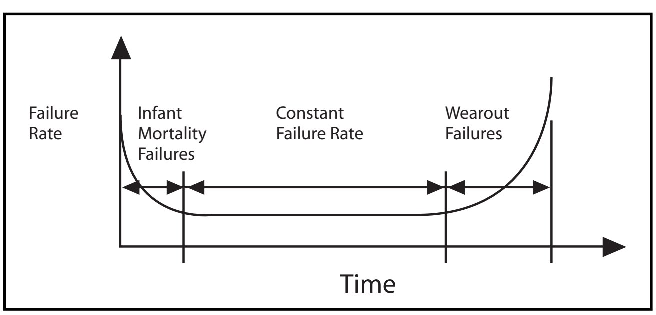


Figure 2. The Bathtub Curve: Applies to No More than 4% of Components in Four Statistically Significant Studies Over a Period of About 40 Years.

Conclusions reached concerning the two profiles that exhibit a wearout characteristic in all studies further undermines the long held basis for preventive maintenance programs comprised largely of intrusive, time directed tasks. These profiles and the associated percentages of components in the four studies further refute the idea that periodic preventive maintenance is the most effective strategy to prevent failures. All profiles exhibiting any form of wear-out characteristic (rapidly rising conditional failure probability) amount to no more than 20% of all components included in any of the studies.

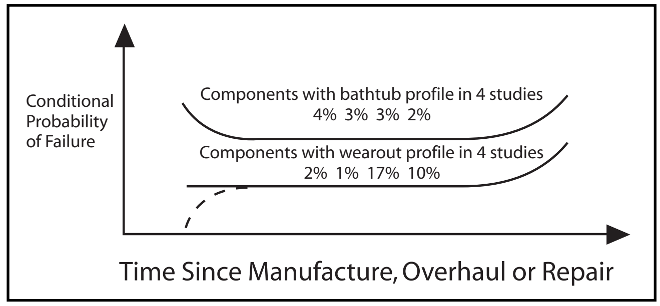


Figure 3. This Point is Illustrated in the Combination of Profiles Illustrated in the Graph. Note that the Totals for the Only Profiles Showing a Wearout Characteristic are 6%, 4%, 20% and 12%, Respectively.

The dominant failure profile for commercial aircraft in both studies was one characterized by the first two parts of the bathtub curve, infant mortality followed by random failures. This characteristic applies to 68% and 66% of components in the two aircraft studies. No wear-out appears anywhere in the profile. In surface warship (MSP) study the infant mortality profile applied to 29% of components. In the nuclear submarine (SUBMEPP) study most recently completed the profile applies to only 6% of the many components included.

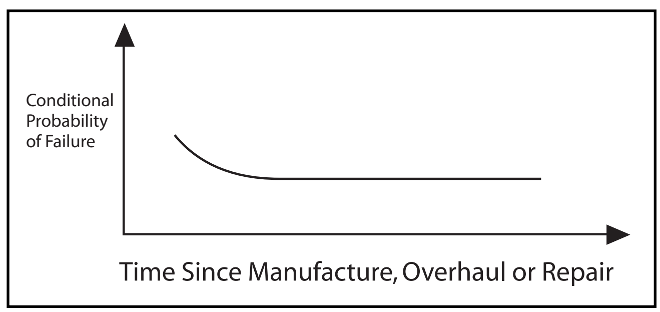


Figure 4. Infant Mortality Failure Profile : The Dominant Characteristic, 68% and 66% in Commercial Aircraft Studies in 1960s and 1970s, but Only 29% in Surface Warships Studied in 1980s and 1990s and 6% in Nuclear Submarines by 2001.

Infant Failures and Planned, Time Directed Tasking: "It Wasn't Broke, but We Fixed it Anyway!"

To understand the wide difference between these numbers (68% and 66% in the 1960s and 1970s, 29% and 6% in the 1980s and in the 1990s, a review of the evolution of maintenance for the machines involved in these studies during that period is in order. In commercial aircraft maintenance, operational time (at intervals not to exceed 1000, 2000, 5,000 10,000 hours, etc.,) dictated when specific preventive maintenance checks and replacements were to be done. U.S. Navy preventive maintenance for surface ships and submarines was based on calendar time (monthly, quarterly, annually, etc.). Many of the required inspections were intrusive, requiring varying amounts of disassembly. Licensed commercial aircraft mechanics and electricians and "qualified" military technicians relied upon the skill-of-the craft, intuition and on-the-job training more than written procedures. The use of detailed, printed step-by-step procedures was in its infancy. If they existed at all, they were in technical manuals delivered when the equipment was new. Manuals were rarely kept up to date, thereafter, because of lack of funding. Navy crews were required to extract, reproduce, promulgate, and update maintenance procedures, but the local capability to do so was totally inadequate. None of the tools needed even existed on board naval vessels beyond manual typewriters and Mimeograph machines. The labor and expertise in procedure writing required far exceeded the capacity and capabilities of the crews.

Recognizing this, the Navy began to develop and promulgate detailed maintenance procedures from shore based support activities in the 1960s. Technical manual content and/or manufacturer's recommendations were used only as a starting point, and largely disconnected from procedures, thereafter. Civilian contractors directed by naval field activities that supported the fleet developed most procedures. The contractor personnel actually doing the work were predominantly former naval technicians with expertise in the systems and equipments.

The reasons for developing detailed procedures were compelling. Military personnel rotate frequently from station to station. Their duties change as they are promoted - as frequently as six times in the first eight years in some specialties. Word of mouth and on-the-job training and intuition were simply too unreliable to assure safety and consistency in maintenance practices. There wasn't enough time in a career to promulgate everything through formal training courses. The only logical means of assuring continuous improvement in fleet readiness (maximum reliability and availability) was to implement a comprehensive Planned Maintenance program that was procedure based. At the same time the fleet had to change to assure use of and compliance with procedures, even for the parts of the fleet where the best and the brightest sailors worked (submarines).

At the same time, over several decades in shore support activities and civilian contractor firms, the Navy continuously updated the tools (such as computerized word processing) and technologies (such as electronic image integration into text) needed to generate and promulgate new and revised detailed maintenance requirements documents. In addition, the Navy made shore support activities accountable for promptly responding to fleet feedback and supporting organizations recommending changes to improve procedures and maintenance requirements. Effectiveness in following up on fleet feedback and new condition directed maintenance requirements became a basis for evaluation and promotion of responsible field activity commanding officers.[4] This facilitated the transition from time directed to condition directed tasking as RCM-based maintenance was implemented.

The maintenance profession, in general, underwent a transformation from almost complete dependence on time-directed tasking (preventive or planned maintenance) to much more condition-directed tasking. Within the Navy, programs for operating cycle extension (between overhauls in shipyards) embraced RCM-based maintenance. During the 1980s this converted largely time directed maintenance programs to condition based strategies for about 220 surface warships and 122 nuclear submarines, including all of those in the SUBMEPP study reported in Allen's 2001 paper.3

What is described above accounts for the lower infant failure rates in naval vessels? Given the same type of evolution has occurred in commercial airline maintenance, an updated study of conditional probabilities for today's air fleet would most likely show a significant reduction in infant failures, also.

Condition Directed Tasking – "If it Ain't Broke, Don't Fix it!"

By the 1980s a wide variety of predictive maintenance tools were beginning to appear. Vibration analysis, lubricant and wear particle analysis, infra red thermography, ultrasonic flaw detection, remote visual inspection using fiber optics and other technologies allowed early detection of degradation in many machines and systems. Widespread availability of ever more powerful desktop computers and, customized and off-the-shelf analysis software accelerated and facilitated this revolution in maintenance thinking.

Diagnosis of current condition and prognosis of likely future progression of problems became easier, safer, more sensitive and more accurate (than human senses and intuition) as mathematically and scientifically based methods such as trend, statistical or correlation analysis and pattern recognition came into use. Condition-directed tasking (that is, doing only condition monitoring until condition dictates the need for corrective action) was made possible by predictive technologies and analysis methods. In addition most predictive technologies are non-intrusive, minimizing the need for disassembly or removal of equipment from service in order to detect degrading conditions. As intrusive maintenance requirements diminish, failures caused by maintenance diminish.

Its okay to require time directed tasks, if the basis is sound and the wear-out characteristic is established for the component involved, but don't forget that few components (no more than 20% in the four studies cited) exhibit this characteristic.

Condition directed tasking makes a lot more sense than time directed tasking when considering the finding that no less than 80% of components included in any of the four studies previously cited exhibited a random failure characteristic and no wearout for the majority of their conditional probability period of operation after manufacture, overhaul or repair. The actual numbers for the four studies are 94%, 96%, 80% and 88%, respectively, displaying random failure and no wearout.

Procedure-Based Organizations (PBOs) – "Fix it Right the First Time!"

The single most important reason for the significant difference in distribution of failure profiles and an order of magnitude difference in infant failures between commercial aircraft in the 1960s and nuclear subs in 2001, in my opinion, was the advent of computer based word and image processing programs along with more rapid communications methods. Although rudimentary in the early 1980s, by the mid 1990s they had almost completely eliminated the use of typewriters and hand cut and paste print-masters in support activities and their contractors. Electronic word processing and inclusion of digital images made possible the development and rapid update of detailed maintenance procedures. It is no fluke that only 6% of components in the SUBMEPP study exhibit the infant failure characteristic. Allen attributes the low number of infant failures to thorough testing of submarine components before the ships return to operational service.3 This may be true to some extent, because testing is an integral part of the repair procedure in most cases. However, infant failures occurring while testing during shipyard overhaul or operational site refit pier-side and on sea-trials are not documented in the data gathering system used to record failures during operational periods. Work orders are not closed out until the operational testing is completed to the satisfaction of the operator (ship's crew).

Equally likely, in my opinion, is the fact that submarine maintenance and operations personnel are required to comply with detailed procedures (which include post maintenance tests and instructions for returning the system to a ready to operate condition) in performance of repairs and to conduct in-service preventive maintenance of all types. The result is that they fix it right the first time.

At the upper end of the procedure hierarchy are Controlled Work Procedures. These were introduced for nuclear submarines in the 1970s and for surface warships in the 1980s.[5]

In submarine maintenance, detailed procedures are required to be used for repairs and in-service preventive maintenance of all:
- Submarine systems
- Nuclear reactor, propulsion and electrical and auxiliary systems
- Sensor and Fire Control Systems
- Weapons systems
- Life support systems
- Emergency systems.

Skill-of-the-craft based-maintenance practices are permitted for:
- Hotel systems (Plumbing, cooking, water cooler, soft drink and ice cream dispensers, etc.)
- Entertainment systems
- Auxiliary lighting and systems (e.g., reading lights for berthing, etc.)
- Interior communications systems not designated as essential for ship operations.

In the mid 1970s, it took over 18 months for a substantial change to a maintenance procedure to be disseminated fleet-wide. In the late 20th Century, a small change to a maintenance procedure, such as a revised safety precaution, could be transmitted by naval message to the whole fleet in less than 24 hours. But a more substantial revision could still take months to be fully disseminated. By the beginning of the 21st Century, a whole new maintenance procedure can be originated and transmitted to the whole world via the Internet in a matter of hours.

The basic conclusion reached concerning all of this is that infant failures in maintenance are caused by lack of procedures and/or failure to follow and learn from procedures. The more detailed the procedures and the more insistence on compliance with procedures an organization becomes, the more precise and less error prone its maintenance will become. The result will be an increase in reliability closer to limit that design and other factors will permit.

So our answer to the challenge about how to do maintenance is - become a Procedure-Based Organization – a PBO. That's a buzz-phrase that you can take to the bank!

A Procedure-Based Organization produces or receives and complies with detailed written instructions for conducting not only maintenance, but also operations and routine checks. This seems so basic that it is overlooked in most organizations and for all the wrong reasons! It's so much easier than it used to be, given availability of low cost word processing and scanning and image insertion equipment, that there is hardly any excuse for not doing it, given the benefits derived in terms of increased reliability. The fundamental approach is depicted in the diagram below.

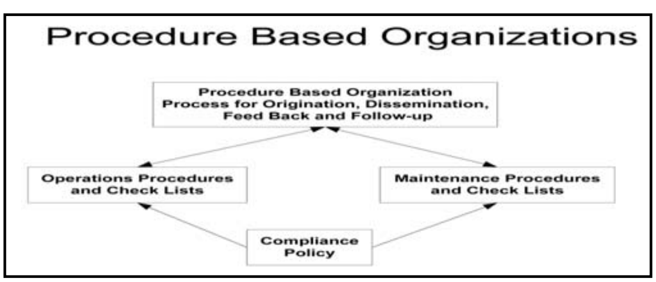


Figure 5. This Diagram Emphasizes Two-way Communications to Sustain Health of a Procedure-Based Organization.

Not only does an activity have to declare that it has a Procedure-Based Organization, but it has to back it up with a working process for procedure and checklist origination, dissemination, feedback and follow-up. The idea of feedback and follow-up is reinforced in the diagram above by arrows that imply two-way paths for communications. It is not enough just to disseminate procedures and checklists. Users must have on-going evidence that their ideas for improvement are being received, considered and acted upon promptly. Changes that are concurred in must be seen to be incorporated in revised procedures and checklists coming out of a process that functions as well as is expected of the maintenance and operations processes it supports. Otherwise, enforcement of a policy requiring compliance will quickly become impossible, because of a perception that management support for the process is weak or non-existent.

In July 2004 co-author of this paper, Jack Nicholas, had the opportunity to conduct a one-day seminar in response to a query concerning what it took to become the world's best maintenance organization. The organization had been operational for only 18 months after rejuvenating a portion of a steel plant that had a hundred year history before shutting down and going out of business three years earlier. The new organization was doing quite well, having returned the equivalent of 80% of its new owner's investment in the short time it had been operating under new management and carefully selected staff. However, all there knew that world steel prices, then inflated due to the China Bubble, could very quickly deflate to where they might not be competitive with other suppliers of the product they manufactured. They saw maintenance as an area where their equivalent profit margin (return on investment to their owner) could be improved. After attending the seminar, which stressed use of detailed procedures and checklists for both operations and maintenance, management decided to apply the principles to startup of one of their most complex manufacturing processes. They prepared a check-off list for start up of all systems needed to roll steel bars into coils of wire ready for shipment.

About two weeks after the seminar, the leader followed up with the company president to see how it had been received. The president volunteered that they had applied the rolling line startup check-off list for the first time that week. They decided to run the check-off twice before the first bar of steel was introduced to the line. They found in the second check that they had missed two items the first time. After correcting these items during the second run-through of the checklist the startup went without any delay or incident, a first for that plant under the new staff. If ever there was a "Hallelujah Moment," for one preaching the benefits of detailed procedures and checklists that was it!

This is not in any way to denigrate the methodology called Total Productive Maintenance (TPM). There are elements of TPM, such as the use of checklists for inspections, which if done properly and by the right personnel (operators in many cases rather than maintainers) will also enhance maintenance excellence and reliability derived from it. However, the checklists must be definitive enough to be effective in the hands of the least experienced person responsible for conducting them. When a particular inspection is called out, definitions of what one would be expected to see and what is acceptable and not acceptable must be spelled out in every case.

Under TPM methodology, while operators assume maintenance tasks, maintainers become free to enhance their skills through training and adoption of new tools such as predictive maintenance technologies and analysis methods. The end result is to move towards mastering maintenance by learning how to do it.

From the Depths of Despair to Record Profits at Dofasco

In 1993 Dofasco, a fully integrated steel producer located in Hamilton, Ontario, Canada, was experiencing the effects of comparable but lower cost steel products from overseas eroding profits to the point where the directors seriously considered having the company go out of business.[6] Dofasco managers decided that the company might survive if manpower was severely cut and the remaining staff retrained, supported with productivity improvements and machinery upgraded for improved reliability. In the 18 months that followed about 35 % of those employed were retired or accepted buyout offers. About 5%of the almost 14,000 employees were laid off. Subsequently, those who were still available were recalled in the next year as retirements, buyouts and deaths occurred.

The effect on staffing and organization of this very paternalistic company was dramatic. Over the years, successful crafts-persons were retained at Dofasco by placing them in supervisory positions where they could qualify for higher pay. With the downsizing and reorganization between five and six layers of supervision were eliminated. While one would believe this was a good thing, a very significant capability was also lost – that of preparing and supporting a very substantial set of procedures and check-lists. One of the major functions of the personnel occupying the lost positions was to prepare, review and approve procedures for corrective and preventive maintenance jobs. These had been incorporated into Dofasco's Computerized Maintenance System (CMS) so that when a particular job was called out, the procedure for conducting it was printed out to become part of the package that accompanied the work order placed in the hands of personnel assigned to conduct it.

The procedures were quite detailed and provided a considerable legacy to those that remained in the downsized organization. They had many unique features and considerable detail in steps, safety requirements and tools and parts lists that were of great value to those doing the work. Recognizing their value, the managers decided that the capability to originate, update and provide continued support for procedures and check lists had to be re-established in remaining staff.

Very early in the long path to restore the company to target profitability, a series of training courses on writing procedures and checklists was conducted for key crafts-persons and first line supervisors.

Subsequently when the CMS was replaced with an updated Computerized Maintenance Management System (CMMS), the procedures and checklists were integrated, also.

The initiative to sustain a procedure based organization was only one of hundreds of actions and projects undertaken at Dofasco to bring the company to the point where in the year 2004 record profits were reported in several quarters. In addition, Dofasco invested some of its profits in and became a partner in a mini-mill in Kentucky and has established new tube mills in Mexico and at its home site in Hamilton, Ontario.

Use of Procedures at U.S. Nuclear Powered Electricity Generating Plants
After the Three Mile Island nuclear powered electricity generating plant incident in 1979, the U.S. Nuclear Regulatory Commission (NRC) began emphasizing the use of procedures and checklists (among many other measures) when carrying out both corrective and preventive maintenance on safety related systems of reactor plants. In addition, the nuclear industry's internal watchdog agency, the Institute for Nuclear Power Operations, provides guidance and audits to ensure that procedures, among many other initiatives, fully support the goal of preventing an incident like the one in 1979 or worse.[7] The result for the nuclear powered electricity generation segment of the industry in the U.S. was that it was saved. It produces about 20% of the nation's electricity and has become a nearly irreplaceable segment of U.S. electric power. All statistics describing the performance of the 110 nuclear power plants of the industry are continuing to move in a positive direction. No incident like the one at Three Mile Island has occurred since. The NRC has started to grant extensions of operating licenses for up to 20 years beyond the nominal initial length of 40 years. Although nuclear powered electricity generating plants are not problem-free, the overall performance has improved in all but a small number of plants to the point where new, inherently safer U.S. originated designs are being accepted, built and operated internationally. The new designs are likely to be built in the United States within the next few years.

An interesting result concerning use of procedures at nuclear powered electricity generating plants is that owners have found that overall reliability and capacity factor (ratio of actual output of power in a given period of time compared to maximum authorized output, expressed as a percentage) are enhanced when detailed procedures and checklists are used for all systems, not just those that are safety related. This ensures that the maximum number of generated megawatts are available for sale, assuring maximum plant profitability.

How to Become a Procedure-Based Organization

Becoming a procedure based organization first requires the development of a game plan. The value of procedure based maintenance does not lie in the existence of the documents themselves. Rather, the value resides in the experience, ingenuity and engineering that the procedures represent. In other words, important decisions about how maintenance shall be conducted in the organization are codified into a procedure that represents a standard for the organization. This serves the organization in numerous ways (Figure 6). A body of clearly defined best practices enables the organization clearly define what is expected and standardize on that expectation across craftspeople, across plants and, where applicable, across divisions, which helps to assure consistency. Likewise, procedures help to ensure continuity of practice. If a craftsperson resigns, retires, takes ill or for some other reason is not available to carry on the tasks, the codified practice will carry on despite his or her absence.

Increasingly a manager's span of control is increasing. As such, it is becoming increasingly difficult for managers to evaluate the performance of an individual based upon an inherent and deep understanding about the job his reports are required to carry out. Codifying procedures, by definition, defines expected behavior. The manager requires only the ability to compare actual behavior and performance to what is expected based upon the procedure. Or, if he or she so desires, the manager can contract or assign the evaluation to another person because the scope of the performance review is clearly defined.

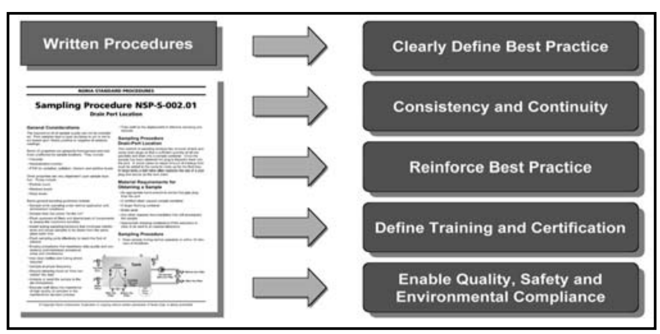


Figure 6. Procedures Capture and Document Good Engineering Practice, Enabling the Resultant Tasks and Activities to be Effectively Executed and Managed.

As a professional trainer/educator, one author has observed numerous clients pursue skills improvement in a somewhat aimless manner on many occasions. Technicians and craftspeople are sent to training (in-house or off-site) to gain new skills and knowledge, while managers anticipate that these newly acquired capabilities will be put to productive use in the plant. In reality, this training is often ineffective because the craftsperson or technician returns to the same old maintenance system that is not conducive to using the new knowledge and skills. As a result, the newly acquired skills atrophy over time. If developed properly, a maintenance system comprised of optimized decisions about what to do that is codified into written procedures provides the framework with which to apply new skills and capabilities. Moreover, the procedures themselves, by codifying work expectations, provide a roadmap for skill enhancement and remediation. Often, we educate people about the basics, but fail to train them on the specific tasks. Procedures create the scope for task-based training.

Lastly, as our activities and actions become increasingly scrutinized by environmental protection agencies, quality standards, insurance underwriters and the like, procedures serve as a basis for defining what we do and how we do it, so auditing to confirm compliance becomes a much simpler matter. Likewise, assuring compliance is much simpler because we must simply work the plan that we've devised and maintain a sensible mechanism by which our maintenance plan may be modified to reflect changes in the business environment, ambient environment, political/social environment, operating context, etc.

Because the procedural standards are bespoke to the organization they serve, the decisions they reflect should incorporate information pertaining to machine design, criticality, operating context, environmental conditions, availability of skills and organizational culture. A discussion of the some key objectives for developing a procedure-based maintenance program follows.

Optimize What Work Gets Done and When

When developing a procedure-based maintenance program, it would be foolish not to take the opportunity to optimize what maintenance tasks get done and the manner in which they are completed. Candidly, a large percentage of preventive maintenance tasks either fail to add value to the organization or, in some instances, actually cause problems themselves. For instance, if motors are greased monthly because "that's the way it has always been," yet a lubrication engineer determines that re-greasing is required only once every six months, five damage causing PM events can be eliminated. Optimize tasks relative to machine criticality/reliability goals, failure history, access for maintainability, available technology and skills, etc. Tap into the collective experience of existing employees, contract retired employees and utilize subject matter experts to develop the work plans. Remember, our goal is not to simply codify bad practice – we want to take advantage of the opportunity to capture best practice and make improvements where possible.

Define the Mechanism by which Work will be Planned and Scheduled

It is well documented in the maintenance and reliability literature that investments in maintenance technology have not delivered the value that was initially expected of them. Computerized maintenance management systems, or CMMS, are no exception. The fault, however, does not reside with the technologies, which are mere tools, but rather, with the deployment plan – which is often sketchy. If management provides sketchy instructions to a craftsperson about how a job should be completed or what is expected, it doesn't really matter whether the instructions are provided via a special software package or written on an index card – the instructions are vague either way. If, however, a well-defined procedure-based maintenance program is developed, a sophisticated computer software-based planning and scheduling software becomes an important enabling tool, which provides access to work plans and supporting documents – a central nervous system of sorts. You'll want to be sure your system can support the document-based maintenance support system you are establishing. Think through this in advance. The availability of software can and should affect the manner in which you design and engineer your procedure-based maintenance program and vice versa – allow the synergy between good planning and the availability of technology to flourish.

Specify any Equipment Modifications Necessary to Achieve Maintainability

Maintainability, as the name suggests, is the degree to which maintenance tasks can be carried out. There are numerous ways in which one can view maintainability. For example, if a machine requires adjustments or inspections to run properly, but the tasks require that the machine be shutdown, the run-time maintainability is poor. Or, if an inspection or adjustment is very time consuming or potentially hazardous to the technician, the maintainability is poor.

If you effectively optimize what work gets done, as was previously suggested, you will probably create a list of required equipment modifications. Unfortunately, years or decades of decisions to design and procure equipment to achieve functional capability at the minimum price often leaves the plant difficult to maintain at the level desired for a modern, reliability focused organization. As a result, equipment modifications are typically required to achieve maintainability and to carry out the optimized work plans. Often, these modifications are minor – in other instances, they are more substantial. In either case, be sure to close the loop with engineering and procurement so that future designs and purchases reflect your current goals for maintenance and maintainability.

Consider the simple example of checking the oil level in a sump. If the tech must remove a plug on the sump in order to check the level, an intrusive, time consuming and potentially dangerous activity, maintainability can be significantly improved by installing a level indicator. This example may sound mundane, but numerous examples of poor maintainability exist in most industrial facilities.

Capture and Codify Optimized Equipment Maintenance Work Plans – the Mechanics

One thing that should ring clear in this paper is that collecting documents is not the objective of procedure-based maintenance. Rather, it is our intent to capture and deploy best practice. However, procedures represent the mechanism by which good decisions and best practice are codified and standardized so that they can be effectively employed and managed. Once captured, the procedures can be managed in paper, electronic or other form. But, there are elements associated with the manner in which the documents are created that you should consider.

When thinking of a procedure, one typically envisions a document that contains a series of instructional steps that are sometimes embellished with pictures and graphics to improve clarity. However, this document can be classified on a fixed versus variable continuum with two extreme ends that we refer to as a hard document or a pseudo-document. A hard document is unchanging. The most severe example of the hard document procedure is the one printed in the OEM manual. To change the document, one must re-create it from scratch by typing every word. On the other extreme, the pseudo document is variable. In the extreme example, every word is housed as a functional relationship in a relational database. Changing any of the input variables effectively changes the procedure. Unless you expect everything in your operation as well as the economical, technological, political and sociological environment to remain fixed forever, it is wise to employ a database structure for building your procedure-based maintenance program.

So, using pseudo documents, when you invoke a required procedure and print it (or load it onto a handheld computer, data collector or personal digital assistant) to assist in task completion, what is printed or downloaded is in fact pseudo document created on demand from the information contained in the database. It requires extra work and planning upfront to build a program this based on pseudo documents, but it significantly enhances ones ability to manage the program ongoing. Consider the simple example of a motor where the motor is removed from service where it drives a fan, sent to the rebuild shop where it is rebuilt, brought back into stores and eventually installed to drive a pump within the plant. Where should the procedures reside? One can argue that the procedures should reside with the motor. Likewise, one could argue that the procedures should reside with the location and/or service. In reality, the procedures must consider the machine design, location and service, and operating environment. If your procedure-based maintenance system employs database-driven pseudo documents, you have the flexibility to manage change over time.

Another consideration in creating procedural documents is the length. Ideally, one would include all the details for completing a task so that a new employ with little experience can be quickly brought up to speed and is not required to fill in the blanks with guesswork that often results in reliability eroding mistakes and inconsistency. However, these documents can be quite long and difficult to work with in the day-to-day planning and scheduling function. One author has concluded from experience that for each fully specified procedure, which we call a reference procedure, a shorter, more manageable form we call the abridged procedure should be created. The reference procedure serves the organization by ensuring that the full details of what it considers to be best practice are maintained intact. Likewise, if a new person is assigned to the job or if the technician hasn't completed the task in sometime, the reference procedures serves as a training support tool. For day-to-day planning and scheduling purposes, however, the abridged procedure is employed. It should contain the essence of the reference procedure as well as the main details required to complete the task (e.g., tighten to the specified torque, apply the specified grams of grease, etc.).

Staff for Success

One extremely useful byproduct of procedure-based maintenance is that by clearly defining what must get done, the required skills and capabilities are clearly defined, which supports training and other human resource functions. Rather than aimlessly providing training, one can create training programs based upon the tasks that will be assigned to a craftsperson. For that matter, a training module can be created to support any specific task or class of tasks. Once the required skills are defined, audit existing skills and remediate as necessary. Be sure not overlook the need to educate before training. Education provides a foundation that enables an individual to think in a particular way. Training, on the other hand, teaches the mechanics of carrying out a specific task. One is educated to think like a lubrication engineer or technician and trained to carry out periodic decontamination of a gearbox. The education enables the individual to understand why cleaning the oil extends the life of the gearing and bearings in the gearbox and the training teaches the individual how to get the job done – both are required for success.

Once you've concluded what skills are required, you must audit your organizations existing skills versus required skills necessary to complete the planned work and train your staff to remediate and/or enhance skills required to carry out the work defined by the procedures, or hire or contract workers to complete non-routine or highly specialized work.

One of this paper's authors is routinely questioned about who should do work of a particular type – operators, mechanics, contractors, etc. The answer really depends upon your organizational culture and the nature of the work. It is beyond the scope of this paper to deal with that topic in detail - suffice to say that the greater degree to which you decentralize maintenance work, the more important it becomes to posses clearly defined maintenance procedures. The more people you have performing maintenance, the more important it becomes to be mechanical in your management methods. When only one or two people perform all the maintenance tasks in an organization its easy to have confidence that those people will do the right thing assuming they are well qualified and experienced. However, when maintenance activities are divided among dozens (or hundreds) of maintenance workers, operators and contractors, one can't assume that they'll all perform to specification without the mechanical support of well-defined procedures.

For maintenance tasks that are contracted to outside firms, the procedures play a duel role of defining how work is to be completed and defining the scope of the relationship. Many a maintenance contract has gone foul due to the lack of a clearly defined scope. Usually, failure can be attributed to the fact that the contracting organization and the service organization had different views about what was expected. Bad contract waste time and can erode equipment reliability. A clear set of maintenance procedures gets the contractor and the service organization in proper alignment.

Continuous Improvement

As with any program, once procedure based maintenance is established, it is imperative to continuously monitor its effectiveness and modify as required. Likewise, as the design and/or operating or environmental context of the plant and its assets changes, the maintenance program must be modified to reflect the new reality. The documents supporting your maintenance program must change according. Changes in technology and/or knowledge about maintenance best practice should also be incorporated into your procedure-based maintenance program to keep it fresh and up to date. So, be sure to organize the program so that changes can be made globally, by plant, by area, by service type, by machine type, by task type, by criticality, etc. In other words, build the ability to continuously improve into the program.

CONCLUSIONS

Procedure based maintenance organizations already exist in commercial, utility and government sectors. Many programs were established after a major crisis, disaster, or near disaster forced the organizations into initiating many actions, of which the use of procedures and checklists was only one. Most were procedure based programs were established because it was more profitable than the old way of performing maintenance.

It is difficult to distinguish the benefits from procedures and checklists exclusively from the skill and effectiveness with which the tasks are carried out. However, common sense combined with the logic of the statistics derived from study of failure profiles makes a compelling case for procedure based maintenance. Procedure-based maintenance captures decisions and best practices in a manageable form, which helps to assure consistency and continuity of best practice, provides the backbone fro training and skills management, including contract management, serves compliance requirements and serves as the basis for continuous improvement. In addition, the confluence of inexpensive, modern word and digital image processing technology and the ready availability of many non-intrusive, predictive, condition monitoring technologies make it possible to conduct of maintenance with assurance of sustained reliability. Many other benefits flow from the use of detailed procedures and checklists, including the capability to improve output as well as improved and/or sustained product quality.

There is really no valid excuse, today, for not moving towards procedure based maintenance. The basic conclusion is worth repeating. The more detailed the procedures and the more insistence on compliance with procedures an organization becomes, the more precise and less error prone its maintenance will become. The result will be an increase in reliability to as close to the limit that design and other factors will permit.

References

1. Photo appears in Nautilus: The Story of Man Under the Sea by Roy Davis, USNI Press.
2. (USS Scorpion (SSN 589) was lost later in the 1960s, due it is now believed, to a faulty torpedo. Root cause is believed to be a design flaw in the torpedo propulsion system battery, causing it to explode in the torpedo room while it was being serviced and dooming the ship and its crew, including the Commanding Officer, who had been Mr. Nicholas' roommate on Nautilus in late 1963 and early 1964.)
3. The four studies from which failure profiles and statistics are taken are: "UAL Study" - DOD Report on Reliability-Centered Maintenance by Nowlan & Heap of United Airlines, dated December 29,1978, which used data from the 1960s and 1970s and earlier papers and studies referenced therein; the "Broberg Study" believed done under sponsorship of the European Airline Maintenance Study Group (reported in 1973) and cited in Failure Diagnosis & Performance Monitoring Vol. 11 edited by L.F. Pau, published by Marcel-Dekker, 1981; the "MSP Study" - long title "Age Reliability Analysis Prototype Study"- done by American Management Systems under contract to U.S. Naval Sea Systems Command Surface Warship Directorate reported in 1993 but using 1980s data from the Maintenance System (Development) Program; and the "SUBMEPP Study" reported in 2001, using data largely from 1990s, and summarized in a paper dated 2001, entitled "U.S. Navy Analysis of Submarine Maintenance Data and the Development of Age and Reliability Profiles" by Tim Allen, Reliability Analyst Leader at Submarine Maintenance Engineering, Planning and Procurement (SUBMEPP) a field activity of the Naval Sea Systems Command at Portsmouth NH.
4. In the late 1970s the Director of Fleet Maintenance, an admiral in the Naval Sea Systems Command, upon hearing of the poor track record of field activities in responding and acting upon feedback on maintenance procedures from the fleet and from other fleet support organizations, embarked on an 18 month crusade to improve the system. He made it clear to responsible field activity CO's upon whom he wrote fitness reports that they had to make this improvement in responsiveness or suffer consequences in terms of his recommendation for further promotion. The system improved dramatically during that period.
5. A handbook for writing controlled work procedures was developed in the Naval Ships Systems Command and widely promulgated to submarine repair activities in the late 1970s. In the 1980s the high rate of infant failures and rework problems in surface warships came to the attention of the Surface Force Atlantic Fleet Commander, who, upon hearing what the submarine force had done, ordered a handbook, tailored to surface warships, be prepared and distributed. Subsequently, it was promulgated to all naval surface warfare vessels and supporting activities throughout the Navy.
6. In the ten years following 1993 over 40 North American steel companies entered into bankruptcy and either stopped or radically reduced production to only the most profitable lines. Many were merged with other producers and disappeared as separate entities.
7. The Chernobyl Nuclear Plant disaster in April 1986 in the USSR was caused directly by the use of a test procedure that had not been reviewed or approved by the authorities responsible for reactor safety. The explosion, fire and recovery efforts killed and injured hundreds of plant and responder personnel and resulted in the permanent evacuation of over 15,000 residents from towns nearby because of deadly levels of radioactive contaminants.

Planning and Scheduling: The Basic Keys

By Arne Oas, Computerized Facility Integration

ABSTRACT

The key to any successful Planning and Scheduling program is the proper deployment of basic strategies that don't change regardless of the size, complexity, or nature of the organization: management support, work control, work estimation, and work coordination. For management to support the program they need to understand that a problem exists and what proper planning can do to solve it. Work control or the management of how work gets done: procedures must exist and be followed. Identification of work and material requirements needs to be done, but to what level? And that basic work coordination of material, job, and schedules requires everyone to understand and perform their role.

This seminar is aimed at giving the attendee a fundamental understanding of why a planning initiative makes sense for their business, what elements are essential for their success, what they can control, and how to start. If an organization already has a Planning initiative in place, but the results are not meeting expectations, this seminar may point to problem areas and solutions.

Major Topics

1. Planning & Scheduling - Why
2. Planning Staffing Size – What is needed for the organization
3. Work Control – What and Why
4. Planning – What is it
5. Planning – Job Estimating vs. Work Estimating
6. Scheduling – Backlog control
7. Scheduling – Weekly meeting
8. Work Assignment – Daily scheduling and execution
9. Computerized Support – Where to start.

Why Plan and Schedule Work

Why? Marshall Institute developed the following comparison of a normal maintenance to a production operation.

"Could you imagine a production operation where:

- Each operator waiting for someone to tell them what equipment to operate or telling management what product they are going to make?
- Each operator going to stores to get the material needed to make the product as his process requires it?
- Each operator ordering their own material to make their product and then waiting on it?
- Each operator waiting in line to use the equipment to make their product because others needed the same equipment at the same time?
- Operations standing around, watching another operator work, because no one knew it only took one person to run the machine?
- When was the last time a company began production on a product without someone planning - the material it would take, the equipment required, the labor required, and the time required to produce a finished product?"

Poor utilization of a maintenance worker's time is usually not his fault. Nothing is more detrimental to maintenance performance and morale than poorly planned jobs. Planned maintenance reduces the wait and delay times which maintenance workers encounter when doing unplanned work.

In a further effort to explain, the following list is often cited in detailing the areas of lost maintenance time and how those areas affect an average worker.

Total maintenance time available per year -	2080 hrs	100%
Lost time due to:		
1. Vacation, sick days, personal time, & holidays @	208 hrs	10%
2. Training @	21 hrs	1%
3. Administrative (time cards, etc.) @	83 hrs	4%
4. Slack and Personal time @	504 hrs	25%
Sub Total	816 hrs	40%

That leaves:		
Total hours available for maintenance work	1264 hrs	60%
Lost time due to:		
1. Drawing material for each job @	208 hrs	10%
2. Travel to and from jobs @	208 hrs	10%
3. Job preparation & cleanup @	208 hrs	10%
Sub Total	624 hrs	30%
Total hours available for actual work (wrench turning time)	640 hrs	30%

This breakdown of US worker time hasn't changed much since I first saw it 30 years ago. If you do the math, this is about 150 minutes a day.

So, why aren't we more productive? In a report by Proudfoot Consulting the following reasons were determined to be the major cause.

	2002	2001
Insufficient planning and control	43%	43%
Inadequate management	23%	22%
Poor working morale	12%	14%
IT-related problems	8%	8%
Ineffective communication	7%	7%
Inappropriately qualified workforce	7%	6%

Properly identifying work in advance allows coordination with the operations group before the work is scheduled. Proper job and work estimating allow for part and labor requirements which allows for effective scheduling. Then scheduling of a days work (what can reasonably be expected to be done) for each worker, each day eliminates the "fire-fighting" approach to maintenance and reduces slack time associated with waiting for the next assignment. Giving the worker all his jobs for the day, identifying his tool and material requirements, and scheduling work with operations can greatly reduce material drawing time, job preparation time, and travel time. If an average worker does just three jobs a day and you save 20 minutes a job, this will result in about a 40% increase in productivity.

Planning Staff Ratios

Those 60 minutes translate into an improved wrench time of 14% for a total of 44% the average wrench time without planning and scheduling equals 30%. And planning and scheduling can increase wrench time to 44%; the resulting productivity improvement is 46% (44% / 30% = 1.46 or 46%).

For four craftsmen without planning and scheduling wrench time equals 120% (4x30%). With planning and scheduling, one Planner and three Craftsmen wrench time equals 138% - (1 x 0%) + (3 x 46%).

Conservatively, one Planner can plan for 20 craftsmen, then 20 Craftsmen multiplied by 138% equals an increase in effective wrench time to 27.6 people. So, hiring one Planner equates to getting the additional work of 7.6 Craftsmen, (27.6 - 20 = 7.6).

That should get management support and attention.

Work Control

The first big challenge associated with implementing a Planning & Scheduling (P&S) program is work control. Before worrying about optimizing Preventive Maintenance (PM) work, expanding Predictive Maintenance (PdM), or MRO Inventory (Parts) identification, you have to be in control of your work process.

What is Work Control? Work control is the generic term used to talk about the process an organization uses to identify, manage and control how work gets done and documented. In order to assess your current work control processes you must fully understand them. Start by asking the following questions:

1. How does work get identified? Who enters it into the system?
2. How does it get selected for work? Who should approve jobs?
3. How is the work planned? How are required parts identified and ordered?
4. How does it get scheduled and assigned?
5. How does all this information get recorded? Work orders? How does that get back into the system?
6. And finally how does the recorded data get analyzed?

Typically, there are three distinct types of work: Scheduled (your current PM/PdM), Projects/Capital (Engineering and Outage) and Repair (planned and unplanned).

Scheduled work is the heart of any planning department because it drives everything else in your site's operation. In addition to extending equipment life, these tasks should identify any problems with the condition of the asset. As a base load they should be about 35% of your total reported hours.

Project or Capital work is usually major work by nature and generally does not deal with day-to-day problems of the maintenance department.

Repair work has two categories: what you know about (your backlog) and emergencies (the things that go bump in the night). It doesn't matter which of these we talk about, they are identified in the same manner: through PM/PdM inspection; supporting system generation (control, DCS, BMS, etc.);or customer identification of a problem or issue. If properly designed, PM/PdM inspections should be generating 50% of your total workload.

Repairs are the problem children in the work control group. Why? Just ask these two questions: Do I fix it now or can it go into the backlog? And, who is going to enter the request into the system?

The "Do I fix it now or can it go into the backlog?" question can be answered for the most part by pre-established Work Priority and a few simple questions. The questions:

1. Is it life threatening?
2. Is it a major safety item?
3. Will continued operation result in equipment or facility damage within 24 hours?
4. If identified on a PM, do you need less than 15-20 minutes to repair the problem?
5. If identified on a PM, no parts are required to repair the problem?

If the answer is yes to any of these you may want to respond immediately and fix the problem first, documenting it after the fact. If no to all the questions, then it should probably go into the backlog. The use of pre-established jobs (standard repairs) in the CMMS can help here. Having the responsible person or craft, estimated times, WO Codes, and response times established lets you standardize repair data for further assignment and analysis.

The question of "How work is entered into the system" depends on how your CMMS application is deployed, your organization structure, and your culture. If the CMMS is designed to allow anyone in the organization access then obviously anyone can enter a work request (client, portal, web, etc). If not, some sort of help desk will be required to assist them. Also, do your technicians document work and the results? If not, the supervisors or person closing the work order will have to enter the information for them.

Getting all of your work (past, present, and future) into the system and documented is critical to controlling it. It is also the first step in planning and scheduling. After all, if you don't know what work you is out there, how can you expect to control it and perform it effectively?

Planning

In its traditional thought of form, Planning consists of scoping and estimating jobs. In reality it can be broken down into 2 distinct functions: Job Planning and Job Estimating. Job planning is determining what is to be done and how it is to be done. Job estimating consists of determining the resources: craft skill, time required and material requirements to accomplish what needs to be done. Planning often gets confused with scheduling, which is determining when a job will be done based on manpower, operations or production schedules, and part availability.

What does planning do for you?

A Planning program usually has seven objectives. They are:

1. Provide maintenance with a program that integrates with production schedules to promote the best utilization of the maintenance and production personnel and equipment.
2. Obtain optimum maintenance on equipment and facilities at the least cost.
3. Reduce downtime and breakdown time.
4. Maintain accurate records.
5. Provide information for required inspections of equipment and facilities.
6. Eliminate craft conflicts or restrictions through proper identification.
7. Allow for the determination of proper levels of inventories of parts, tools, and other resources.

The normal Workflow for the job is usually something like the following:

- Work is requested and approved by the area supervisor. A priority is given to the job by that supervisor. The work is then forwarded to the planner.
- The planner will then investigate the request and inspect the work site. The permits, materials and tools needed are determined. An estimate of the manpower required to perform the work is made.
- The work is moved from a request to a work order. The planning function begins. The area, priority, and resource availability will determine the scheduling.

- The planner determines the availability of material, initiates stores disbursement or purchase requisitions, and arranges for delivery of the parts to the job site (staging area).

- The planner then determines if a Standing Job (work order) for future work should be developed around the new plan.

- The scheduler then coordinates work with production or customers to determine an optimum time to perform the work based on their schedules. Estimated manpower is examined for that time frame and, based on priorities, the work is then scheduled. Work is scheduled for the maintenance team by group, by day and delivered to the supervisor of that group. (The scheduling piece usually involves the coordinating of contractors and central shop functions.)

If this sounds fairly simple, why are there so many consultants out there teaching planning and scheduling? It could be because there are no textbook answers on how to organize a maintenance group or support the planning/scheduler function.

Why no answer?

Basically, it is because no two maintenance organizations are exactly the same. They are different in regard to their mission, resources, facilities, or equipment to be maintained. So what works for one organization may be entirely inappropriate for another.

Because of all the requirements of the planner function, I find that one planner can handle somewhere around a 20-25 person maintenance department. This will change based on equipment types, organizational structure, level of planning required, and exact position duties. Note, this position is not that of a clerk. While approval of changes to the PM system and other CMMS routine functions may be part of the job, the hands-on performance of those changes is not part of the planner's responsibilities. If CMMS updates and administration are included, the worker to planner ratios drops to 15 - 20 people.

Also, don't forget that not all work needs to be planned; for example, normal daily routine work, emergency, and repairs of less than 2-4 hours may not require formal planning.

Scheduling

The accomplishment of proper scheduling requires the establishment and control of a maintenance backlog. As mentioned above, within the maintenance work order system, when a person notes a problem or wants work done, it goes into the maintenance system as a "Work Request" and is assigned a work order number. The requests are reviewed for approval and either expedited, if an emergency, or held for scheduling, if non-emergency. Approved, non-emergency requests need work requirements developed, so the work is moved to a planning queue. Once planned the work from the queue then becomes the backlog. The backlog then is the record of requested jobs that have been approved to be worked on, planned but not yet scheduled. It is the heart of efficient workforce utilization and scheduling, because it is the primary means used in balancing requested or required work with the available workforce. The correct allocation of personnel to required areas of work is essential if prompt response and proper management of maintenance resources is to occur. Priorities within the work order system, availability of parts, personnel, and equipment criticality should all be used to determine when and which work will be performed.

The size backlog is also critical to perform effective scheduling. Too small of a backlog does not provide enough of a work cushion to allow for smooth scheduling, it can cause transfers or layoffs of personnel. Too large of an equipment backlog may give the requestor a feeling that the work will never be done (with a good percentage of them being right). Therefore the scheduling team needs to monitor the size of the backlog by total hours of estimated work divided by total weekly labor hours available. For most organizations, a backlog should be greater than 2 weeks but less than 5 weeks. If the backlogged work is outside these limits (longer than 5 weeks) other solutions should be considered, such as contract work, overtime, or canceling jobs. Any job and its priority that has been in the backlog for more than one year should be re-evaluated.

Proper control and scheduling of this work order backlog is fundamental to successful maintenance operations. To assist in this control a Backlog Report should be developed. The report should contain the work order number, the equipment (location) identifier, equipment (location) name, Relative Importance Factor (RIF), a brief description of the problem or work to be performed, type or skill of the personnel required to complete the work, the time required to complete the work, and the status (in planning, awaiting parts, ready, open) of the work order.

A copy of the Backlog Report should be printed and distributed to the planning and scheduling team on a weekly basis. This team should be made up of production (operations) and maintenance personnel. Individually the team members should review the backlog (both PM and repair) and determine if unusual parts or special scheduling is required to complete the work. They should note these requirements on the report. Then the backlog should be reviewed weekly in a group setting with the entire team. Combined information about equipment availability and special parts orders should be noted by the individuals who will actually be scheduling performance of the work on a master Backlog Report.

A sample agenda for the meeting is as follows:

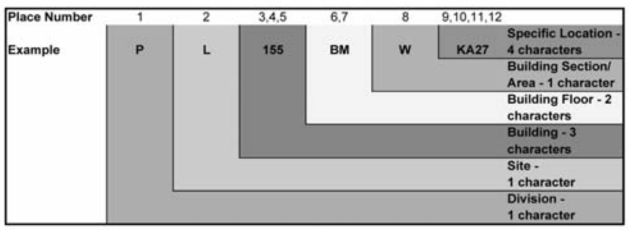
A) Planning Issues (10 minutes)
B) Backlog Status Review (5 minutes)
   1. Number of total jobs
   2. Jobs waiting on planning
   3. Jobs waiting on parts
   4. Jobs ready to schedule
C) Priority Issues (15 minutes)
D) Backlog size and required action (10 minutes)
E) In work status review (15 minutes)
F) Review shutdown schedule (10 minutes)

In the meeting remember work should only be scheduled if parts are available, the manpower is available, and the equipment is available. In addition, the work should be scheduled utilizing some kind of an importance evaluation scale.

After the meeting, a person(s) should be assigned to schedule jobs for either people or crews. To reduce overall maintenance cost and improve work order execution, it is necessary for maintenance supervision to learn how to schedule their workload. Scheduling should start by dividing the work among the people/crews available for work the following week. This assignment must be based on the work shown, the equipment or location, access required for the work, and knowledge of the personnel/crews capabilities. Any special instructions should be noted on the individual work order (parts, times, scheduling constraints, etc.). After completely assigning all the work, each person's or crew's workload is reviewed to ensure that they are not overloaded and the workload has been properly distributed.

WO Priority	Type	Minutes to Respond	
9	Life / Environmental	5	
8	Emergency	15	
7	Housekeeping	60	
6	PM	20160	14 Days
5	Scheduled	20161	14 Days
4	Routine	90720	63 Days
3			
2	Project	90721	63 Days
1			

There are also some important structures that need to be put in place to support the planning effort. The most significant of these structures are the hierarchies: System, Location and Equipment. These will be the way you navigate and find equipment or locations in the CMMS.



Sample Location Hierarchy

Almost at the same time you are developing the equipment hierarchy, will have to determine what makes up different types of equipment. While seemingly simple, correct identification is crucial in the efficient operation of your maintenance organization. This equipment design will drive future problem analysis and impact your ability to identify and control work.

The next development will involve equipment and location coding. The coding system is used to identify and track the history of the equipment and location, while at the same time facilitating ease of use and administration. One suggested code consists of a 3 digit alpha designator followed by a 5 digit numeric code. For example: AHU00001 or PMP00237.

What You Own

Knowing what you own is extremely important. How can you plan work or tell someone to work on something if you don't know it is there? Typically, I find only 1 in 20 companies have actually ever done a field verification of the equipment data in their CMMS within the last 5 years, if ever. Without a survey, you will find it difficult to know what you own. While you perform the verification, tag your equipment. Tagging insures that everyone is correctly identifying equipment for PM and repair. If they are not tagged, can you readily identify which pump is #1, and when it was serviced last, when does the warranty period end, etc.?

You know what you own. You know where it's located. So what's next? How important is the equipment to your operation? Will the unit shut down your entire process, a line, or is it just an annoyance? How fast should your staff (in-house or out-sourced) respond to a reported problem? Determining the criticality of the location or equipment is crucial in determining its reliability requirements and subsequent service. This is not just a simple 1, 2, 3 ranking. And it does not just involve the maintenance department determining what's important. Operations, Safety, Environmental and Quality Departments all need to be involved and help determine how important any item or location is to your entire operation. Start the development of the ranking with simple functional system diagrams. Define the system, show connections (supplies and outputs) and show all equipment and critical instrumentations. This will help to determine the impact of system loss or failure of the equipment.

This ranking will be the driving force in determining repair response times, work scheduling, the development of order preventive /predictive maintenance requirements and Bill Of Material (BOM) development.

Define The Repetitive Work

Develop your PM/PdM inspection requirements by equipment/location classification and the associated criticality. PM/PdM is the heart of the Planning function, and should be about 30% of your workload. Because of its repetitive nature, it needs to be planned only once. If properly designed, these tasks should identify 50% of your total maintenance work.

In addition, have you ever looked at how much value your current PM's add? It is often cited that more than 50% of all PM's are "pencil whipped" - reported done, but not actually completed. What we have found in practice is that:

- 30% could add value if they were re-written
- 30% should be replaced by a PdM
- 30% do not add value and should be deleted
- 10% add value as written

You can use RCM or just a plain old review. When reviewing, pay attention to replacing current PM with PdM. (And remember to delete the old PM.) This is what the world-class operations are doing. This is also a good spot to develop failure hierarchies that you will need for reporting. You have to know how it fails to prevent or detect the potential problem.

Staff Requirements Estimates

Now knowing what you own and how it is to be serviced you can determine manning requirements. Look at your PM/PdM program staffing requirements. One method I use starts by identifying the hours required to perform PM/PdM on you equipment by type. You then identify the number of types of equipment and multiply it out. You can further break the hours on equipment by craft to get a more detailed staffing level.

Equipment Class	Count	Annual Hours/Class	Total Hours
AIR HANDLER	78	21	1638
AIR MIX UNIT	546	0.5	273
AIR_CONDITIONER*HEATPUMP	140	8	1120
AIR_CONDITIONER*PACKAGE	194	5.2	1008.8
AIR_CONDITIONER*SPLIT	45	5.2	234
AIR_CONDITIONER*WINDOW	59	1	59
BALER	1	2	2
BATTERY	46	4	184
BMS	2	20	40
BOILER	18	20	360
BURNER	22	0.5	11
CHARGER	23	0.25	5.75
CHILLER	23	40	920
CHILLER PROCESS	20	40	800
CLEANER*AIR	10	15	150
COMPACTOR	3	4	12
COMPRESSOR		5	0
COMPRESSOR*AIR	51	2.5	127.5
COMPRESSOR*CENTRIFUGAL	11	20	220
CONDENSER	70	2	140
CONTROLLER	381	0.5	190.5

Then estimate for normal repairs (no project work) and add that to the PM. This will let you know what staffing level is required to maintain your equipment. The following is an estimating ratio that has worked well for several companies.

Repair Work Allowance

Overall	1.7 X PM Hours
Electrical	3.0 X PM Hours
HVAC	2.5 X PM Hours
Lubricator	0.3 X PM Hours
Mechanic	1.5 X PM Hours
Plumbing	6.5 X PM Hours

You then estimate your non-wrench turning time and project time as a percentage of the PM and repair time. This varies greatly depending on your organization and facility. The total is then divided by 2080 hours in a year to come up with FTEs for that craft.

Staffing Requirments	General	HVAC	Chiller
Est. PM Hours	7917	8298	5611
Estimated REPAIR Hours	11876	20746	14027
Non-Wrench Time*	19793	29044	19638
Estimated Total Hours	39585	58088	39276
Equivalent Staffing	20	29	20
Total Staffing	68		

- Remember to take into account unreported and travel time. It should be adjusted for your specific operation. Dividing the result by 2000 hours will give you an estimated manning level; if you are dealing with an older workforce with more vacation, sick time, adjust accordingly.

With estimated staffing levels identified, you can then evaluate the feasibility of achieving your goals for the maintenance organization and for the PM program. Quite often this evaluation leads to a realization that the total number of staff is correct but the number might not be right for individual crafts.

Bill Of Materials

The last support area we will mention is Bill of Materials (BOM). World class organizations average over 60% BOM development for their equipment. This is more than the parts identified by PM requirements and less than the list of parts shown in the vendor's technical manuals. These are the common assemblies and parts used to maintain a piece of equipment. You can't just dump the manufacturer's list in here. Why? One, because they show everything and make the lists hard to understand and two, BOM's are driven by your maintenance and purchasing practices. For example, if you replace a certain type of motor, rather than rebuild it, you won't show the bearings on the BOM.

For proper planning to take place, the planner needs to know what MRO parts are used by a piece of equipment or at a location. Because of the importance to the whole organization the planners should devote about 15% to their time to compiling and getting this information into the CMMS.

CONCLUSION

Although I hope this paper can help your organization in some way, the essence of the planning and scheduling function comes down to a quote from about 350 BC:

"First, have a definite, clear practical ideal; a goal, an objective. Second, have the necessary means to achieve your ends; wisdom, money, materials, and methods. Third, adjust all your means to that end."-- Aristotle

Managing Motors and Reliability

By Elmer DeForest, Snell Infrared

Many are aware of the use of motor circuit analysis and infrared imaging in a predictive maintenance program for motors. When performed properly motor circuit analysis and infrared imaging increases uptime, reliability and productivity, ultimately impacting the thing most managers want to see: Lowered or stabilized maintenance costs. However, the benefits and impact an effective motor management system can have on that cost may not be fully understood.

This paper will discuss the basic key elements for a motor management system and provide an understanding of why a motor management system is much more than just a reliability and testing program. In fact, motor reliability and testing are two key components that make a significant contribution to a motor management system.

There was once an employee that asked lots of questions. This caused a great deal of consternation among the bosses and fellow workers. Aha! The bosses thought, we will promote him, then the can answer his own questions. They continued on, happily thinking this was the answer. However to their chagrin more questions followed.

In the meantime, this newly promoted supervisor was given approximately nine hats to wear. One of them was the Motor Shop. So where else could one start? With a little bit of authority that accompanied the promotion and an A-team was created. A few questions got answered and a few things changed. Before anyone knew it, a motor management system began taking shape.

The first six months were very difficult indeed and another twelve rough months would pass. After eighteen months a faint glimmer of light could be seen at the end of this tunnel. Though people had fought tooth and nail against it, a few eyes began to flutter and some popped open when it was pointed out that repair, inventory and purchase costs had been reduced approximately one million dollars. Suddenly, the questions and ideas put forth, and the actions already taken no longer seemed so trivial.

Looking back one could see the well-traveled road littered with the debris of good intentions, false assumptions, erroneous information, insufficient information, etc. All this and more created a climate where bad decisions were made and money wasted. As an example the first practice stopped in those first eighteen months was repairing motors for nine hundred dollars that only cost two hundred dollars when new. This was only the tip of the iceberg!. Energy consumption issues were later added to the equation, as well as other reliability principles and testing.

What is it?

Managing motor assets require that a motor's location, function, repair, testing and reliability history be documented. Preferably in one place. This documentation should be easily accessed for research and used to assist in making correct and appropriate repair/replace decisions.

Motor testing does not create a motor management system but should be a key component.

Key Components

At a minimum a motor management system should have the following components:

- Motor Manager: someone in charge and accountable.
- Storage - outdoors is not acceptable.
- Preferred and accountable repair facility.
- Repair specifications for the repair facility to use.
- Cost saving contract for purchasing new motors from a primary vendor.
- Reliability testing: Off-line, on-line, infrared and even vibration.
- Acceptance testing of repaired motors and new motors if possible.
- Tracking motors from purchase through scrap and history in between.
- Decision Tree for determining repair versus replacement.
- System to address energy consumption and efficiency.

Who's in Charge?

The person in charge (motor manager) does not have to be a motor expert, however, they should be somewhat knowledgeable of motor basics. They also need knowledge of the motor contract with the preferred new motor vendor and the preferred motor repair facility. The motor manager manages all aspects of motor purchases, repairs, modifications, history and disposition. The motor manager should be a member of the site equipment reliability team and should interface often with the reliability manager on matters pertaining to motor testing and reliability. Managing motors does not have to be the only area of responsibility of the motor manager. They can wear other hats as well!

Figure 1.

Once an effective motor management system has been in operation for a time and employees and other managers become educated as to how it works it should become easier to manage.

Storage

Motors should never be stored outdoors. Ideally they should be stored in a climate-controlled facility. Climate controlled storage facilities are rare.

Warehouse personnel are normally tasked with the day-to-day activities of normal motor storage from receiving, issuing to and shipping to the repair shop. Personnel should be familiar with how to handle and store motors to avoid incidental damage during the storage process.

Large AC motors (high voltage) sometimes need special handling and storage areas. Motors with internal heaters should be connected to a voltage source while in storage to keep windings dry.

Repairs

Every effort should be made to identify a preferred and accountable motor repair facility within a reasonable driving distance. Preferred meaning a facility that can handle just about everything that is sent to them. They should not object to inspection visits and should warranty their work in some manner and work with the customer on all levels of repair. Repair quality and reliability should be the guiding criteria.

Figure 2.

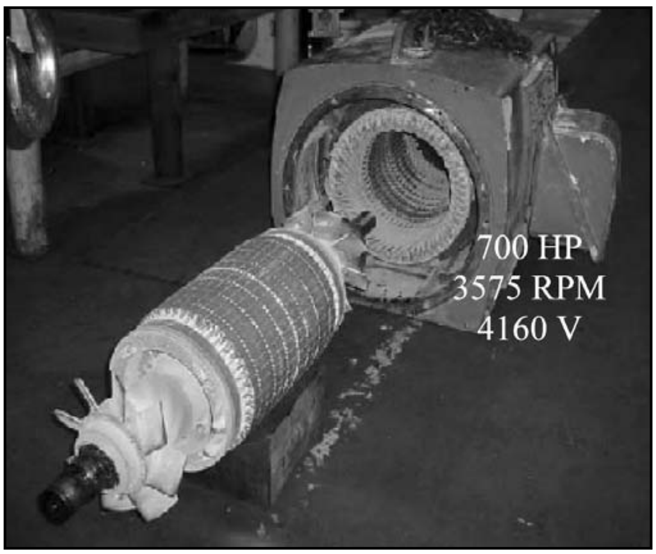


Figure 3.

A contract with a preferred repair facility can be negotiated to reduce repair cost over what it may have been. An ideal situation would be that the repair facility is also a dealer for the preferred new motor vendor.

Then there are the special, one-of-a-kind and non-standard motors that should be considered. Has anyone seen the suffix TY, TCY, TZ, TCZ, etc. (example: 286TCZ)? If so, they are the non-standard variety and might only be acquired from an OEM, not the motor manufacturer. If the OEM is totally out of business (not acquired by another company) a replacement motor may not be available. Having the right repair facility can come in handy with these motors. Also having an understanding of what alternatives are available and knowledge of what to use as a substitute, things can keep running!

New

Anyone operating without a preferred new motor vendor contract could be losing money.

A contract with a preferred new motor vendor may reduce purchase prices by twenty to forty percent.

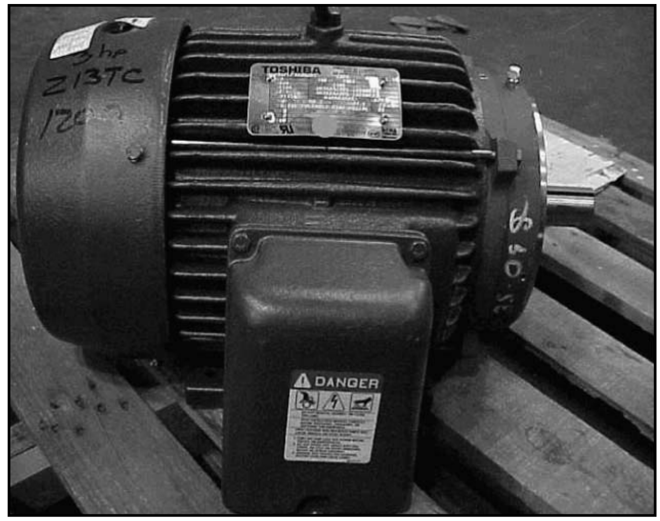


Figure 4.

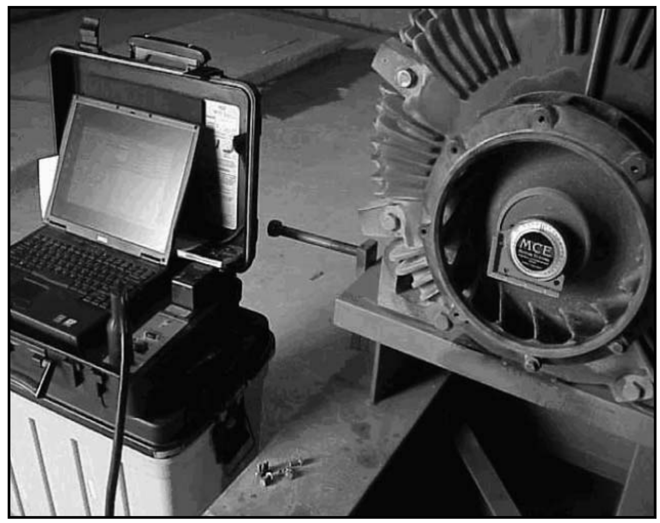


Figure 5.

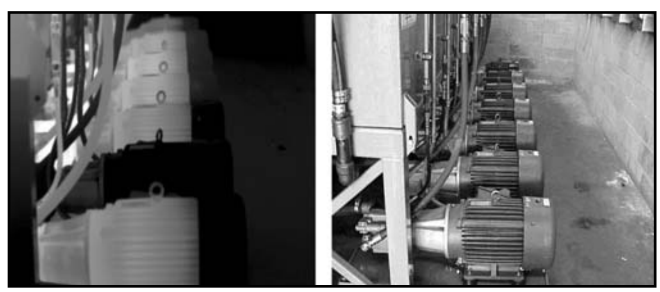


Figure 6.

Large corporations may already have a contract with a preferred new motor vendor. This should be followed whenever possible within the guidelines.

Reliability

Reliability consists of many things such as Engineering, testing and inspection:

- Engineering: Is the motor designed and/or repaired to perform the task it is asked to do?
- Testing: Motors and their circuits.
- Infrared: Baseline images and temperatures of normal are very important.
- Vibration: Baseline data.

When testing or inspecting a motor it is important to ask: Is this the motor I think it is?, or Was this the same one that was there the last time?

A motor reliability and testing technician should not be considered the motor management manager. However, the technician is a key partner in the management of motor assets as well as maintenance managers, mechanics, warehouse personnel, purchasing personnel and etc.

The reliability and testing technician should also have a working relationship with the preferred repair vendor to assist in problem resolutions.

Decision Tree

Every motor management system should have a decision tree. The tree should be used to assist in making repair or replace decisions.

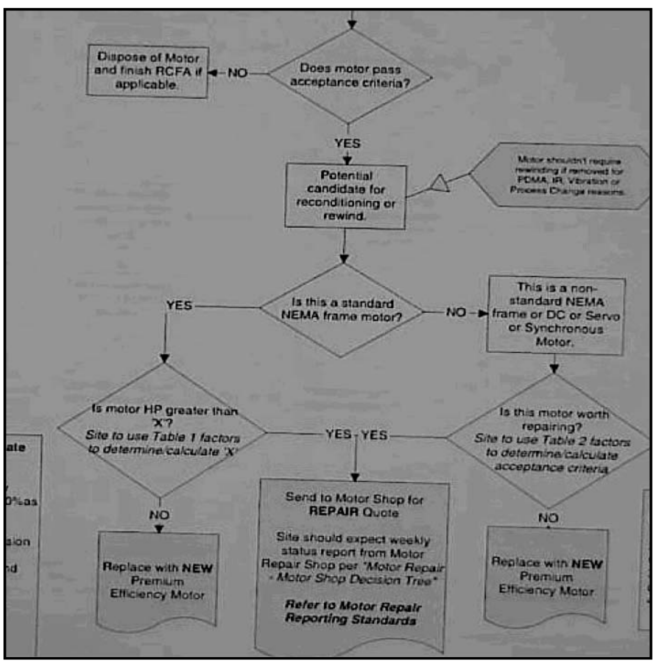


Figure 7.

The decision tree at right is for representation only. It is not complete and also relies on information from a table and another decision tree that are site specific.

Most decision trees I have seen lack one important item – at least in my estimation. This is a branch or section to help determine whether a motor should be equipped with a roller bearing on the shaft end. This is a critical decision for motors driving equipment through belts. Do not construe this to mean that all motors driving belts should have a roller bearing on the shaft end. Each case should be considered separately as to whether a roller bearing would be applicable. This issue is also very important when making a purchase decision for a new motor.

Tracking

Tracking a motor from birth to burial is difficult at best. A properly functioning and effective motor management system makes it easier and can pay for itself in man hours saved, energy efficiency, reduced inventory and above all reliability.

A key element to tracking is assigning a unique identification to each motor. The identification should not be removable. I prefer engraving the unique identifier on a motor. Engravings are not easily removed and remain legible for years of service and more often than not will outlast the motor.

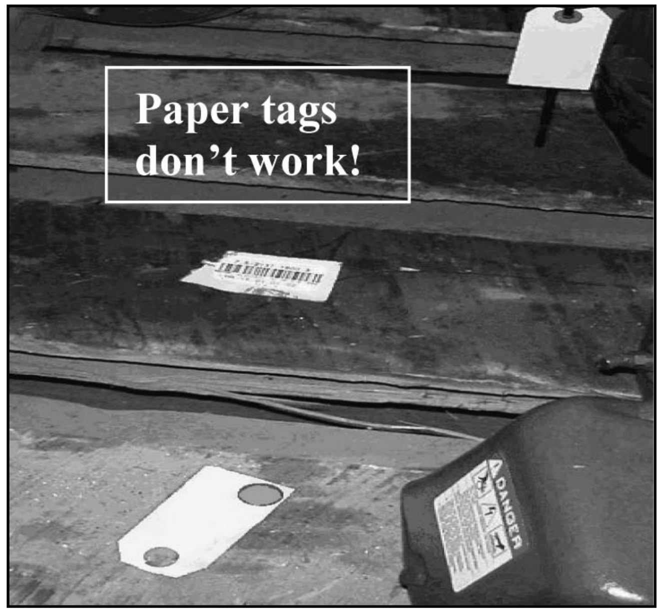


Figure 8.

The area where the J-box is mounted normally provides a large enough surface area as do other areas on the motor. Do not engrave end bells with the identifier in the event an end bell is replaced. The engraving should be as deep as possible and legible. Stamping is not recommend because there is a risk of cracking the casting. Relying on the nameplate for identification can be frustrating, especially if the nameplate is removed or becomes unreadable because of corrosion, etc. Motor shops often install a replacement nameplate but only the basic information is usually put on it and other important information may be lost if not recorded somewhere else.

There are a number of ways to set up an identifier but it should be uniform and not change from year to year. For example, a numeral system based on the year and the sequence the motor arrived can be assigned along with a letter designation for the name of the site. IE: 99-035V. The 99 means it was 1999. The 035 means it was the 35th motor identified in 1999. The V stands for the name of the plant site. If it was an older motor that had not yet been identified it would be assigned the next sequential number.

History

History is a sequential documentary of the life (birth to burial) of a motor. It is a very important piece to help determine whether to repair or replace a motor. Normally a motor stator cannot withstand many burnouts and rewinds without the core becoming degraded. Without a history, it is very difficult to know how many times it has been rewound, much less what else has been done to it or where it has been.

History can be kept in many forms and is normally tailored to a particular site or company. Whatever form it takes it has to be easily used and not fragmented in different places to get a complete picture.

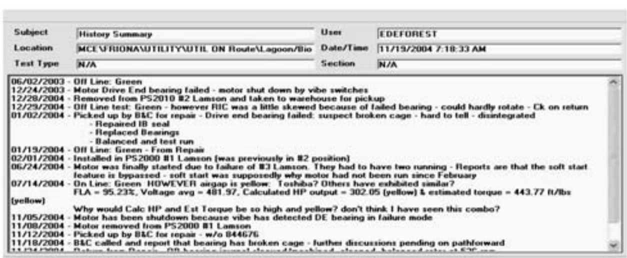
History Sample:
ID: 99-035V **Shop #: 172986** **50-1780-326TPH** **S/N: none**
US Electric 460v 65 FLA 90-eff 82-pf 56 Bars 48 Slots
Note: Open style, vertical mount, shaft down, oil bath top bearing
02/15/1999 – New motor: PO 14598V: Acceptance ck good: Test Run o.k.
02/20/1999 – Installed: 40628971P: #1 River water pump: w/o V179263
10/31/2003 – Removed 40628971P: Grinding noise: No oil: w/o V613578
11/15/2003 – From Repair: Acceptance ck good: Reconditioned
05/16/2004 – Installed: 40628972P: #2 River water pump: w/o V798642

Reconditioned or Basic = Bearings, machining, cleaning, painting and etc.
Overhauled = Rewound along with reconditioned items.

Figure 9.

A number of motor testing systems allow for history entry and retention. However they present some limitations in regard to documenting a complete birth to death history, especially if there is no formal motor management system in place. History then becomes fragmentary and sometimes of little use unless diligently administered.

History is the life-blood of any motor management system and can make or break it.


Subject: History Summary
User: EDEFOREST
Location: MCE\FRIONA\UTILITY\UTIL ON Route\Lagoon/Bio
Date/Time: 11/19/2004 7:18:33 AM
Test Type: N/A
Section: N/A

06/02/2003 - Off Line: Green
12/24/2003 - Motor Drive End bearing failed - motor shut down by vibe switches
12/28/2004 - Removed from PS2010 #2 Lamson and taken to warehouse for pickup
12/29/2004 - Off Line test: Green - however RIC was a little skewed because of failed bearing - could hardly rotate - Ck on return
01/02/2004 - Picked up by B&C for repair - Drive end bearing failed: suspect broken cage - hard to tell - disintegrated
- Repaired IB seal
- Replaced Bearings
- Balanced and test run
01/19/2004 - Off Line: Green - From Repair
02/01/2004 - Installed in PS2000 #1 Lamson (was previously in #2 position)
06/24/2004 - Motor was finally started due to failure of #3 Lamson. They had to have two running - Reports are that the soft start feature is bypassed - soft start was supposedly why motor had not been run since February
07/14/2004 - On Line: Green HOWEVER airgap is yellow: Toshiba? Others have exhibited similar?
FLA = 95.23%, Voltage avg = 481.97, Calculated HP output = 302.05 (yellow) & estimated torque = 443.77 ft/lbs (yellow)
Why would Calc HP and Est Torque be so high and yellow? don't think I have seen this combo?
11/05/2004 - Motor has been shutdown because vibe has detected DE bearing in failure mode
11/08/2004 - Motor removed from PS2000 #1 Lamson
11/12/2004 - Picked up by B&C for repair - w/o 844676
11/18/2004 - B&C called and report that bearing has broken cage - further discussions pending on pathforward

Figure 10. Sample PdMA History

Efficiency

In this day of increasing energy costs, particularly electricity, it pays to be energy conscious.

According to the U.S. Department of Energy: Electric motors consume a large percentage of electricity used in industry across the U.S. On average, approximately 63% of industrial electricity is consumed by electric motors. This percentage can reach 75% or more in certain industries. Also motors can consume five to twelve times their initial purchase cost in energy per year. If one considers that a 25 horsepower motor, running 24/7 can consume up to $15,000 in energy per year and a 100 horsepower motor can consume up to $56,000 in energy per year, even small reductions in energy consumption per motor could result in substantial savings. Additionally, in the case of motors up to approximately 50 horsepower, the savings difference between using a standard efficient motor versus a premium efficient motor could pay for the premium efficient motor in one year. Every year after that would be money in the pocket.

Repair practices and quality can significantly influence energy consumption over original design. A rewound motor, especially if it were poorly done, can significantly increase energy consumption compared to the original as-built specifications: A very important item to consider when making repair and replace decisions.

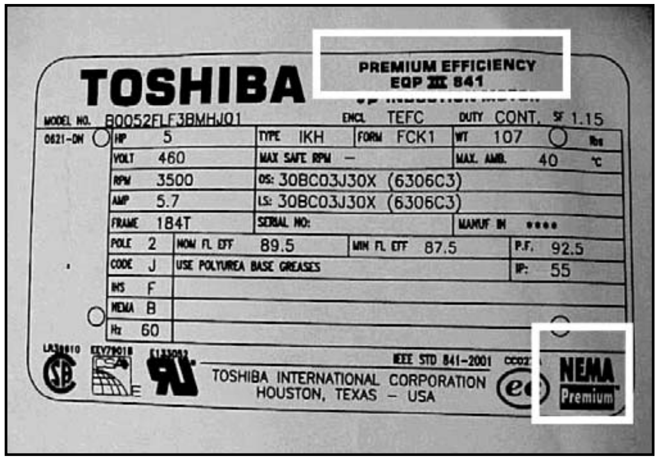


Figure 11.

Having attended and participated in motor management seminars and motor management training sessions normally lasting two to three days I realize this paper and presentation cannot deal with every scenario and address every aspect of motor management. However, I do hope they will be of help in developing more awareness concerning the issue of motor management and its complexities.

A motor management system, functioning at all levels, makes life easier, reduces cost, reduces inventory and reduces energy usage. This keeps everyone happy, including the reliability and testing technician

Take it from someone who has been there on both sides.

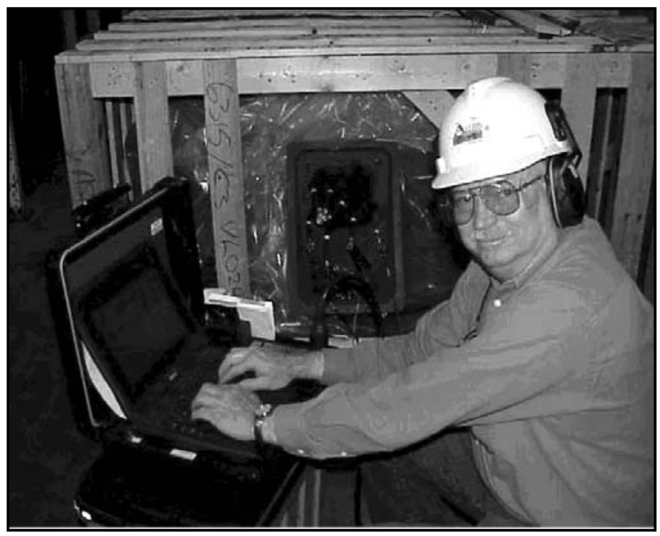


Figure 12.

Using Thermography to Uncover Hidden Problems

By Leith Hitchcock, Pall Corporation

INTRODUCTION

Thermography can be used to identify and analyse thermal anomalies for the purposes of condition monitoring of machines. These thermal anomalies are usually caused by such mechanisms as operation, improper lubrication, misalignment, worn components, or mechanical loading anomalies for example.

Infrared thermography is based on measuring the distribution of radiant thermal energy (heat) emitted from a target surface, and converting this to a surface temperature map or thermogram. Thermal energy is present with the operation of all machines. It can be in the form of: friction losses within machines; energy losses within machines; as a characteristic of the process media; or, any combination thereof. As a result, temperature can be a key parameter for monitoring the performance of machines, the condition of machines, and the diagnostics of machine problems. Temperature is also one of the key causes, and symptoms, of lubricant degradation and loss of lubrication function within a machine and as such thermal imaging is a very useful tool for solving such problems.

Infrared thermography is an ideal technology to investigate thermal anomalies on machines because it provides complete thermal images of a machine, or a machine component, with no physical attachments (non-intrusive), requires little set-up, and provides the results in a very short period of time. As such thermography techniques can be used as part of a condition monitoring process when such a process is implemented in accordance with ISO 17359.

Thermography Techniques

There are several recognized IR Thermography techniques in use throughout industry. Comparative thermography is the most common technique and it is normally used to provide the best available data in lieu of ideal, or absolute, thermal measurements. When encountering changing machinery operating conditions, the ability to perform rough emissivity estimates, and the ability to differentiate emissivity differences on machinery equipment, provides useful information for the condition monitoring and diagnostics of the machine under the less-than-ideal circumstances frequently encountered in the field. Thermometry is used when it is essential to know as precisely as possible the true temperature of a target.

Comparative Thermography

Comparative thermography can be either quantitative or qualitative. The quantitative technique requires the determination of a temperature value to distinguish the severity of a component's condition. This value is determined by comparing the target's temperature to that of similar service equipment or baseline data. Although the temperature value is not precisely exact, it is reasonably close to actual; and, more importantly, the temperature differentials are accurate.

However, there are many applications where quantitative data is not required to monitor the condition of machinery, or to diagnose a problem and recommend the appropriate corrective action. In these cases, qualitative techniques may be more than adequate.

Comparative Quantitative Thermography

The comparative quantitative thermography method is an effective method for evaluating the condition of a machine or component by comparing approximate temperature values between identical items, reference values or baselines. The determination of precise actual temperatures of a component, using IRT in the field, is considered very difficult to obtain. This is due to a certain extent to the physics of IRT which must take into consideration the multiple parameters that enable a true absolute temperature measurement. These IRT considerations are: emissivity; reflectivity; and transmissivity. As a result, estimates of these IRT considerations can be readily made to obtain a component's approximate temperature, which in most cases is more than sufficient to determine the severity of an adverse condition.

Since it is not always practical to determine the exact temperature, or even emissivities, of each machine component, the alternative use of comparative thermography becomes more practical. Comparative measurement, unlike qualitative measurement, identifies a thermal deficiency by comparing the temperatures obtained using a consistent emissivity value (e default).

The temperature differential between two or more identical or similar components is measured numerically. Assuming that the environmental conditions for both components are similar, the differential temperature for the given piece of equipment is recorded as being the amount above the normal operating temperature of the similar equipment.

An example of comparative quantitative thermography would be that, if two or more machines are operating in the same environment and under the same load conditions, and one is experiencing an elevated temperature, this is usually an indication that a deteriorating condition may exist. However, the determination of the temperature difference would then assist in establishing the severity of the condition. In this example, a 5°C differential would be considered minor, whereas a 100°C differential may be considered to be critical. Also, knowing the approximate value of the elevated temperature would provide an indication that the temperature limit of a component may be approaching alarm values. Therefore, while qualitative measurements can also detect deficiencies, it is the quantitative measurements that have the capability of determining severity.

Comparative Qualitative Thermography

Comparative qualitative measurement compares the infrared pattern, such as gear contact patterns, of one component to that of an identical or similar component under the same or similar operating conditions. When searching for differing thermal patterns, an anomaly is identified by the intensity variations between any two or more similar objects, without assigning temperature values to the patterns. This technique is quick and easy to apply, and it does not require any adjustments to the infrared instrument to compensate for atmospheric or environmental conditions, or surface emissivities. Although the result of this type of measurement can identify a deficiency, it does not provide a level of severity.

This IR thermography technique is used throughout most industries. It is very effective in identifying hot bearings or other abnormally hot machine components, hot spots in electrical equipment, undesirable hot electrical connections, leaking or even clogged fluid heat exchange equipment and its components (tubes), and fluid leaks from pressure vessels, pipes, and valves.

Thermometry

The determination of the absolute temperature of a target using infrared thermography is very difficult to obtain because of the many technical and environmental factors involved. As a result, absolute IRT measurements are done only if very precise temperature values, or small temperature differentials, are critical to a process. These determinations are normally attempted only under extremely controlled laboratory type conditions. This type of measurement is not normally used for condition monitoring.

Baseline Measurements

In all cases, it is strongly recommended that baseline measurements be taken of critical plant equipment. This is very important when making later IRT surveys of machines or components and comparing them with previous thermograms of the same machines operating under the same load and environmental conditions. This condition monitoring procedure is useful for identifying developing problems early, thus preventing major maintenance operations or catastrophic failures.

Assessment Criteria

When applying Infrared Thermography to the condition monitoring and diagnostics of machines and their related components, it is strongly recommended that Severity Criteria be established. The Severity Criteria can take two forms; (1) they can be organized into general categories that identify temperature levels, or zones, versus levels of criticality; and, (2) they can be applied to specific machines or components, or to like groups of machines or components. In either case, the levels are established through experience and the accumulation of data.

In practice no singular acceptance criteria is universally applicable to the variety of items and applications existing in industry. Consequently, severity criteria must be developed for each category of equipment based upon its design, manufacture, operating, installation, and maintenance characteristics and its failure modes and criticality.

Severity criteria can be established on individual machines or components. This method is based on many factors, including: temperature rise versus historical data that establishes rate of deterioration and time to failure; criticality of the machine or component to the overall process; location with respect to other materials/equipment should a fire result; safety of personnel; environmental conditions, etc. Applications could include temperature rises of critical machines, mechanical components, bearing temperature rises, electrical supply or connection rises, fluid leakage losses, or even the number of tubes clogged in fluid heat transfer type equipment.

The infrared thermographer may use delta-T (temperature difference) criteria or classify the temperature severity of mechanical system anomalies. These delta-T criteria are usually reported as the temperature rise of the exception above the temperature of a defined reference.

By taking multiple measurements over time of similar components under similar operating and environmental conditions, statistical analysis can be used to set operational limits for trending and predicting the temperature performance of these components. A delta-T system may be used in conjunction with these absolute temperature criteria to rate the temperature severity of an exception above the maximum allowable temperature.

Relative Temperature Criteria

An example of a set of Severity Criteria based on categories and temperature rises above established references is as follows:

- ADVISORY Up to 10°C rise above a reference or baseline
- INTERMEDIATE 10°C to 20°C rise above a reference or baseline

SERIOUS 20°C to 40°C rise above a reference or baseline
CRITICAL in excess of 40°C rise above a reference or baseline

Reference temperatures should be based on temperatures specified by manufacturers, of similar items or groups of equipment, or of components located on the same shaft. Baseline temperatures should be based on historical or statistically derived temperatures established from the specific item, or machine groups, when in the 'ideal' condition.

Absolute Temperature Criteria

The infrared thermographer may use absolute maximum allowable temperature criteria based on published data to identify mechanical system anomalies. It must be well understood that there are two categories of criteria being material and design:

Material criteria are used where the integrity of the material itself is of concern and is the focus of monitoring.

Design criteria should always be used in preference to material criteria as design criteria normally incorporate material requirements. Design criteria are used where the design integrity is the major concern and is the focus of the monitoring. Design criteria are usually cognisant of performance, operation, reliability, and capacity criteria rather than just component material integrity.

When an exception is heating several adjacent system components and a Material criteria is used, the component material having the lowest temperature specification should be referenced as the alarm criteria.

Caution: in most machine cases, the lubricant will have the lowest temperature specification. The maximum allowable temperature should be stated as the temperature above which an unacceptable loss of component life will be experienced due to a loss of lubricant characteristics. Such reductions in characteristics may be immediate (viscosity) or long term (additive depletion). Such criteria will tend to be design rather than material based. This will require application specific temperature criteria despite the possible use of common lubricants

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In many instances the infrared thermographer cannot directly measure the surfaces of actual components. Care and good judgement must be used when applying any severity specifications to actual field temperature measurements taking into account conduction paths, convection, and radiation.

Profile Assessment Criteria

Profile assessment is a process of comparing temperature differences and patterns across a surface. As in any severity assessment process the absolute and differential temperatures and profiles need to be determined for two key conditions being the as new and the 'failed' conditions. Severity assessment is the subsequent process of determining the condition of the equipment between these two conditions.

The key areas of profile assessment are temperature gradients, changes in profile, historical changes, localised differences, absolute temperatures, location of anomalies or profile characteristic relative to the item.

DIAGNOSIS AND PROGNOSIS

Survey Intervals

Survey intervals should be determined cognisant of the rate of deterioration of the expected fault and the behaviour over time of temperature as a representative symptom of the fault. The determination of survey interval is primarily necessary for prognosis accuracy rather than fault identification.

Image Interpretation

From a machinery viewpoint thermal image interpretation is essentially a process of comparing absolute temperature and temperature profiles against design, manufacture, installation, operation, and maintenance criteria.

When using thermography for machinery condition monitoring purposes the operating conditions at the time of each survey need to be known in detail as many changes in thermal profile are operating condition dependant. The design of a machine is essential to understanding component loading which in turn is the primary contributor to thermal profile. It is important that when using thermography to assess machine condition that the machine is viewed as a whole and that each image is analysed as part of a series rather than an individual representation of a localised condition.

CONCLUSION

Thermal imaging is a very powerful correlation technique for other condition monitoring methods. It is exceedingly useful for assisting with solving lubrication issues that are temperature related as it can pin point location, source, and extent of the influencing thermal anomalies as well as determining effectiveness of circulation, control, and cooling systems.

The key point to successful machinery investigation, and solution design, using thermal imaging is knowledge of design, manufacturing, installation, operation and maintenance induced failure modes and their thermal symptoms are paramount. This knowledge is of far greater importance than specific knowledge of the technique, its applications, and it limitations.

How to Implement an Effective Chain Wear Monitoring Program

By Rod Reinholdt, QCTL, Inc.

INTRODUCTION

Chain wear monitoring has been a part of equipment reliability programs since the first link was forged. It is such an integral part of an organization's reliability program that it has become part of industry slang as in the phrase, "A chain is only as strong as its weakest link." Chains are a part of almost every industrial process. They are found in a plant's material handling transportation system, key components in the operation of hoists and cranes, or as a part of the connection that controls a safety stop device. Regardless of its function, the failure of any component that makes up a chain is costly to the owner, if not disastrous. Even though we would all agreed that a chain failure is undesirable, modern industry's chain wear monitoring has remained varied in its approach and frequency. Typically chain reliability inspections are applied through a periodic inspection sampling procedure or replacement schedule. Visual inspections are commonly applied to the inspection of chain for wear identification, which is time consuming to accomplish with tremendous dependence on inspector's experience, attitude, and processing knowledge. Technology exists that makes this costly approach no longer the only available avenue for chain monitoring to today's maintenance departments. The application of infrared photoelectric optical systems allows for inspections that are more precise, less expensive and result in trending information to reduce failure opportunities.

Figure 1. Examples of worn chain pins identified through use of infrared photoelectric chain wear monitoring system.

Explanation of Photoelectric Process

Infrared photoelectric technology is utilized in many aspects of our daily lives without most of us even being aware of its existence. Examples of photoelectric detectors include the sensor components on the most advanced types of security systems, safety controls on door closure systems for elevators and transit systems, and even as bottle fill level monitors in high production bottling systems. The applications of this technology are certainly vast and varied in nature. The basic principle relies upon an infrared light source (transmitter) that generates a pulsed IR beam to a series of infrared sensors (receiver), which in turn monitors that beam. The combination of the transmitter and a receiver is referred to as a photoelectric detector. The transmitter and the receiver are installed on opposite sides of the area to be monitored and a signal is generated when the receiver detects obstruction of the pulsed infrared beam. A car headlight and a photocell could be used in a science project to create a very crude photoelectric detector. The addition of infrared light to this process is due to its increased receiver sensitivity and penetration. Infrared light is a form of electromagnetic radiation similar to radio signals, visible light and x-rays. While infrared energy is similar to visible light and shares many of its characteristics, infrared energy is invisible to the human eye due to its difference in wavelengths. Infrared energy has wavelengths of 0.75 micron to 1 millimeter. The covers on the photoelectric detectors are made of special materials that are designed to block out visible light, while allowing maximum penetration of IR energy. This is what allows the use of infrared photoelectric detectors on a well-lighted factory floor or even in direct sunlight.

Historical Perspective

If most companies were to document their chain monitoring programs you should not be surprised to find statements like "replace chain when conveyor malfunctions during production" or "the last chain replacement was about five years ago and it's due." Even what is viewed as a proactive program for chain wear monitoring has historically used the method of choosing an arbitrary sample of a nominal ten foot section of chain and physically measuring it for stretch which would indicate wear. Obviously there is a significant degree of risk in using this approach. Sampling plans are dependent on the sample providing information that is consistent with the condition of the entire system. Limiting inspection to a ten foot section of chain within a one thousand foot long system sets up a situation where the likelihood of actually sampling the area of worst wear provides detection "odds" that even a Las Vegas gambler would find unacceptable. Another concern is how accurately measurements are being produced when the measurement device is a standard hardware quality tape measure. The historical alternative, visual inspection of chain, can certainly identify chain wear, but once again can the production schedule tolerate the extreme downtime of such a labor-intensive approach, which needs stationary chain to do an adequate inspection? It must be remembered that many types of chain are lubricated or painted and those same coatings that protect chain from wear and corrosion mask typical wear indicators when performing visual inspections. The last approach that is often used is that of periodic replacement based on chain age. This system of assuring chain reliability may help to reduce production downtime but the cost of replacing reliable chain just because it is due can never be recovered.

Infrared Photoelectric Chain Wear Monitoring

The infrared photoelectric instruments specifically designed for chain wear monitoring typically use the referenced technology to accurately measure the distance between the leading edges of each center link on the chain. With accurate link-to-link measurements these monitors can easily identify individual links or pins that show signs of abnormal wear. The unit pictured below is of a portable battery operated unit capable of monitoring all combinations of 3, 4, and 6-inch chain. Alternate units are available that are designed for single pitch chain. These monitors are capable of in-motion monitoring of chain to allow the inspection to be performed without disruption of production. If permanently installed units are utilized continuously monitoring of the chain can be accomplished instantaneously, identifying any chain links that exceed the programmed limits. Both status monitoring units and permanently installed units identify any link that is outside of preset size lengths through illumination of alarm lights identifying the specific problem area. Most units will provide the operator with options as to how data can be processed, providing alternate avenues for monitoring, data review, and problem area identification.

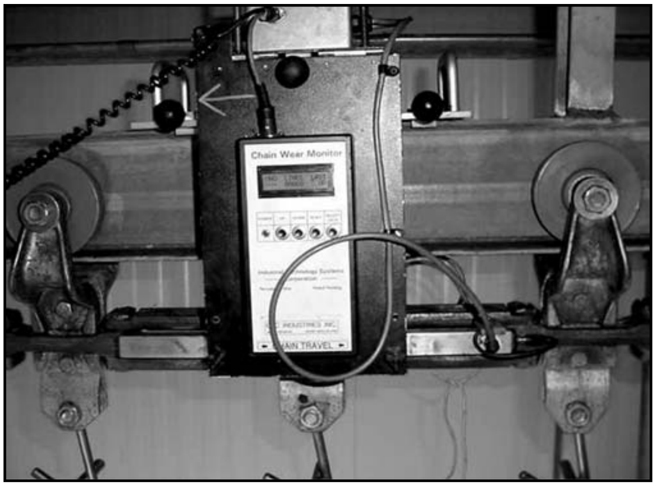

Figure 2. Portable infrared photoelectric chain wear monitoring system mounted on conveyor.

Automated abnormality identification and marking systems identify each link that is above the wear threshold, and, if combined with trend analysis software monitoring, either periodic or continuous scanning will allow for planned replacement of chain only when it is truly needed. Trending software requires a defined start/stop point to allow accurate comparisons. This is usually accomplished through a uniquely identified link installed in the system. An option for start/stop link identification can be accomplished by permanently mounting a magnet assembly in the chain itself, which will automatically signal the unit to start and stop the data recording sessions each time the magnet passes unit sensors. This option provides easily understandable data presentation.

Several unique features that can be obtained from specially-designed software allow for valuable analysis tools such as adjustable span length acceptance criteria, data recording measurement ranges (individual link, individual link sets, or ten foot sections), trending overlay and charting options.

Accuracy

In normal usage chain the majority of chain wear occurs at the friction points. The friction points are those areas where the pin engages the center link. Wear occurs either on the center pin itself or on the inside of the center link, or in most cases a combination of both. Manufacturers provide replacement growth charts which will provide a value which determines the maximum length of "chain growth" that is recommended as a guideline for chain replacement. This is usually based on inspection data that is gathered from the commonly performed nominal ten-foot measurement technique. An example would be that a ten-foot section of new chain measured at 120 inches should be replaced when it reaches 124 – 124.5 inches in length. A concern that should be recognized is that wear may or may not be evenly distributed across that measured section of the chain. The wear on one link may be much more severe than on an adjoining link. This type of condition presents the possibility of a chain on the verge of failure measuring well within acceptable tolerances. The use of individual link measurement technology eliminates this type of error increasing the reliability of the inspection and reducing the risk of catastrophic chain failure. A scanning infrared photoelectric system provides accuracy within $\pm$ 0.02 inches. This is even more significant when the user recalls that this is being measured on in-motion chain.

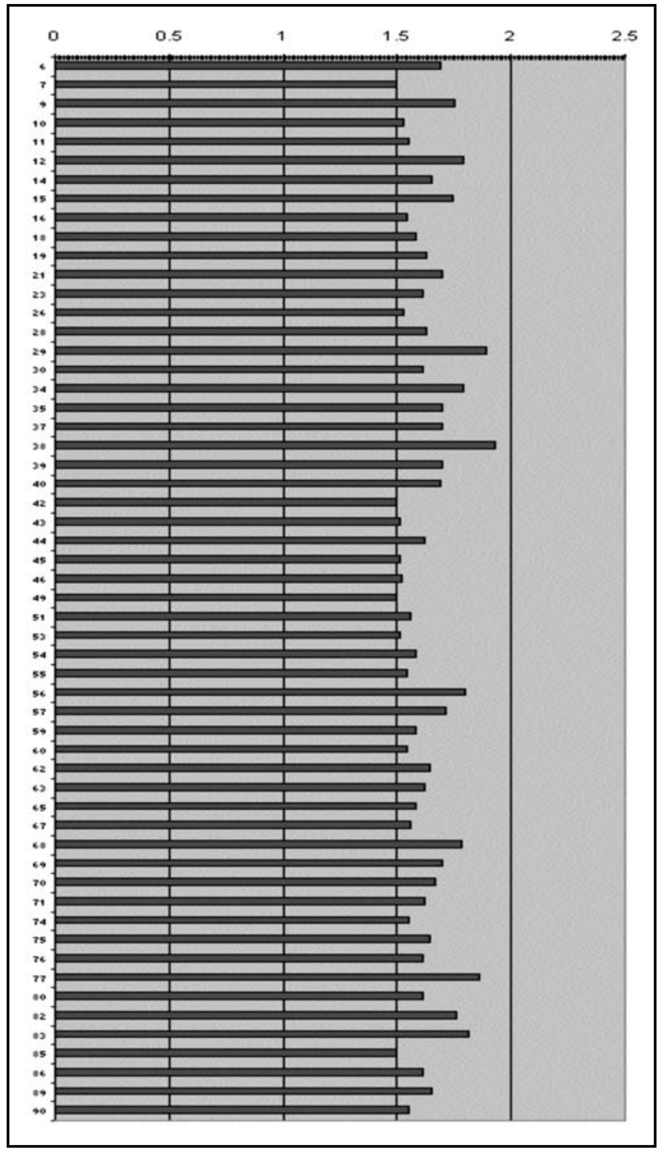

Figure 3. Example of reporting software showing bar graph of link set measurements.

Figure 4. System equipped with automatic paint sprayer marking system designed to mark individual links, which are not found to be within acceptance tolerance limits.

Operating Personnel

Although operation of standard infrared photoelectric chain monitoring systems is not much more difficult than the operation of a typical desktop personal computer there are considerations which should be evaluated when operating this type of system. The first and most important is that of safety. Anytime personnel is required to physically work around moving industrial equipment there are safety issues that need to be carefully monitored. Safety training should, at a minimum, include OSHA safety training and plant specific safety review, and lock out and tag out procedures must be followed to prevent chain movement during monitor installation and removal. Operator training depending on type of unit being inspected needs to address powered chain unit operation (conveyors, cranes, lifts, etc.) unit installation, line walk down requirements, software operation, file storage and recovery and data interpretation. Often two-sided access to chain is not possible and may require sight cut outs. This operation requires an individual that understands the load requirements of various types of units to prevent structural weakening of required supports. Since this type of inspection is reliability based and is not a code, requirement acceptance criteria needs to be established in order to provide useful data. The development of maximum growth tolerances requires individuals with experience in its development. Recommended training and experience may vary, but a good guideline would include 30 hours of classroom style training covering all related subjects and a minimum of 6 months hands-on experience before considering an individual qualified to perform inspections independently.

Summary

The utilization of infrared photoelectric technology to accomplish chain monitoring is a major improvement leap in this important part of a company's reliability program. The cost savings alone justify the research as to the applicability of this technology. A recent example of cost savings was developed by a meat processing company that used the nominal ten-foot measurement technique for inspection prior to implementation of this technology. Over a two-year period their incidents of breakdown were reduced by 100% (Average of 7 breakdowns per 12 month period to 0 unscheduled breakdowns). It was calculated that each breakdown cost the company $2,416.00 in maintenance repair costs, $3,765.00 in lost labor time and $1,184.00 in production revenue. The total cost to the company was $51,555.00 annually. Additional cost savings were realized in chain life extension, replacement part inventory reduction, planned maintenance scheduling and extended chain replacement. This is only one of many examples in which, if chain dependability is critical to plant production or safety of personnel, the utilization of individual link inspection methods are self-funding in their application.

Audible, Visual, and Tactile Inspections for PdM Technicians, Operators and Maintenance Personnel

by Lance Bisinger, Universal Technologies, Inc.

Abstract

Data collection is the backbone of any vibration monitoring effort, yet opportunities to gather additional data while at the machine are typically ignored. Is the vibration industry finally beginning to feel the effects of the pure data collector who has not transitioned into the reliability group from the mechanical trades? What about the site operators and craftsman? This paper covers basic inspection techniques that can be applied to optimize time spent in the field.

Introduction

Many organizations separate personnel who perform technology monitoring into a PdM team or reliability group. Their job is to periodically collect machinery information using various forms of technology and use this data to assess the condition of the machine. Different technologies exist for monitoring the condition of mechanical and electrical components, and especially for detecting impending failure. Each technology has it own applications, advantages, and disadvantages. Effective condition monitoring makes use of multiple techniques and technologies.

An under-utilized group of checks that provide valuable data are basic visual, audible and tactile inspections. These inspections can be performed and used to supplement the formal technology inspections. The key to successful implementation of a visual, audible and tactile inspection program is training the participants on the basic operation of the component to be inspected and following a list of items to be checked.

Condition Monitoring Steps

Effective condition monitoring programs consist of four (4) major elements:

- Detection
- Analysis
- Correction
- Verification

It is important to thoroughly understand each of these elements. Valuable time is too often wasted when too much emphasis is placed on any one component.

Detection

Many problems can be found using visual, audible and tactile inspections. The goal is to identify bad machines or identify deteriorating conditions. The question becomes how to quantify the results of these inspections. Technologies like vibration, thermography, ultrasound, oil analysis and motor circuit testing may be used.

After identifying machines in need of further analysis using detection, the next step is to determine the root cause of the problem. This is achieved during the analysis phase.

Figure 1. Problem Detection

Analysis

The purpose of performing an analysis is to determine the root cause of the problem. The analysis phase involves studying the machine's operation, defect characteristics, maintenance history, etc. Only the machines indicating problems should be analyzed. Once the analysis is complete and the root cause of the problem found, the results should be communicated.

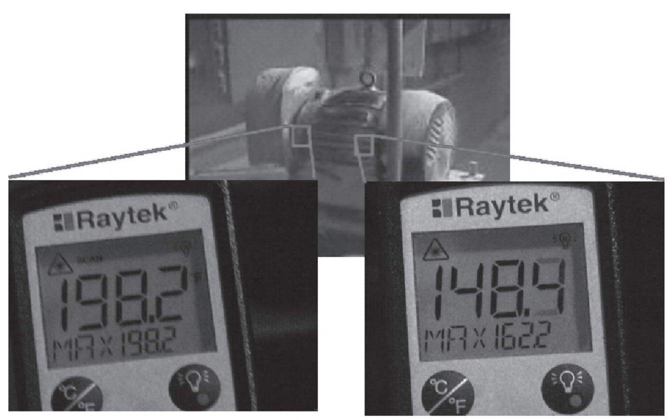

Figure 2. Problem Analysis

Correction/Improvement

After determining the root cause of the problem, it can be corrected. The most common problems require balancing and/or precision alignment. In order to maximize the reliability of the machine in question, it is also advisable to improve the source causing the asset to be in exception. This will extend the life of the machine. We at Universal Technologies emphasize that the incremental time required to improve the machine is small compared to the costs of the unanticipated machine downtime and the maintenance process.

Figure 3. Problem Correction

Verification

After determining the root cause of the problem, correcting the problem, and improving the machine, it is important to verify that the correction or improvement has occurred. One mechanism for this verification is comparing before values to the original baseline data.

Other common verification methods include:

- Tracking increased bearing life
- Tracking increased seal life
- Measuring reduced energy consumption
- Measuring vibration
- Thermography
- Oil Analysis
- Motor Current Signature Analysis

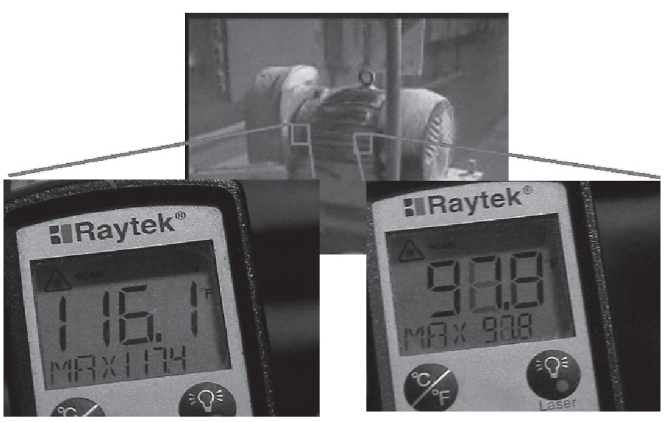

Figure 4. Correction Verification

Visual Inspections

One of the simplest, but often neglected, forms of condition monitoring is visual inspection of machinery. While this is subjective, one can often gain a good "gut feel" for where the problem is most severe. But remember, the root cause cannot be determined in this manner.

Effective visual inspection procedures include examination of the machine and surrounding area for each of the following:

- General cleanliness
- Oil/fluids on surrounding machine
- Oil/fluids on machine casing or bearing caps
- Oil/fluids on coupling guard
- Unusual marks
- Visible leaks (lubricants, cooling water, etc.)
- Lighting conditions
- Local instrumentation for proper levels, temperatures, flows, and amperage
- Fretting and wear particles
- Corrosion
- Signs of overheating
- Proper operation of slinger rings
- Condensation/water in bearings
- Differential temperatures, pressures and flows
- Loose parts or components
- Machine guard or cover condition

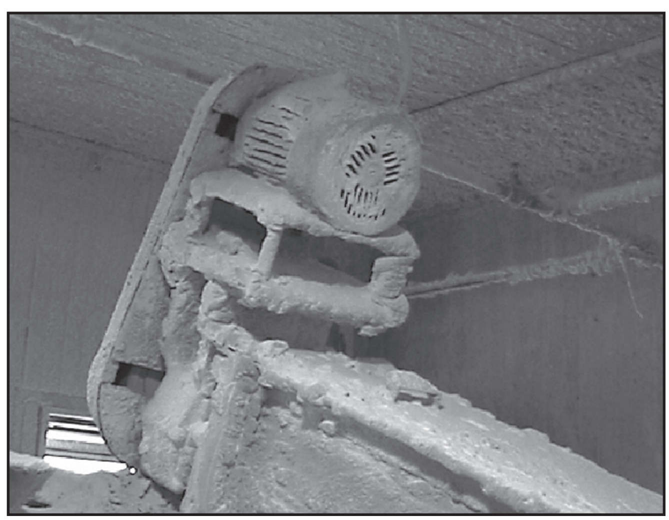

Figure 5. Housekeeping

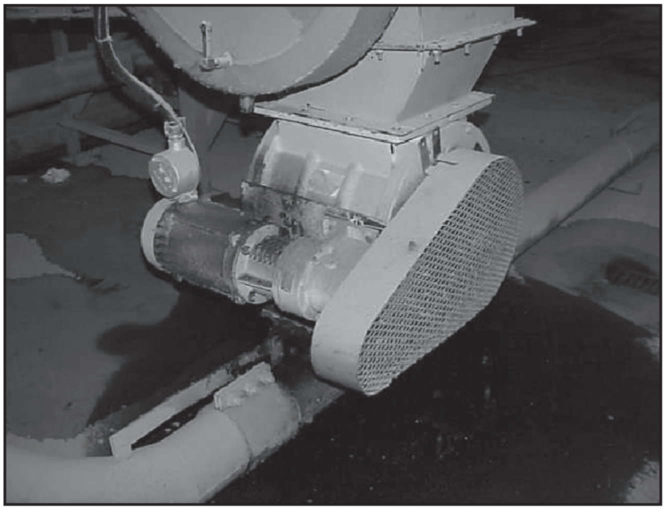

Figure 6. Oil Leak

Figure 7. Frame Crack

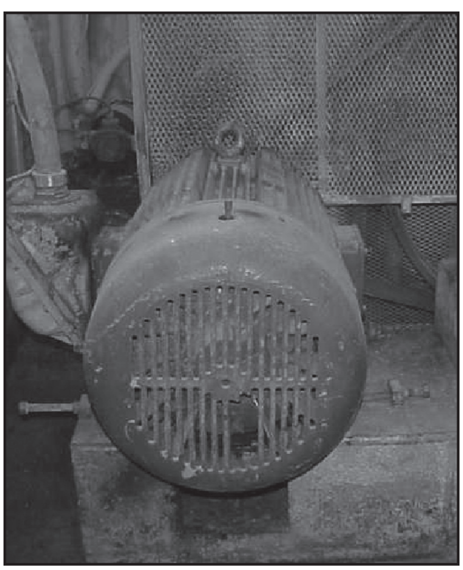

Figure 8. Motor Fan Cover

Figure 9. Oil Condition

Audible Inspection

Another simple form of condition monitoring is audible inspection of machinery. While this is also subjective, one can often gain a good "feel" for the area where the source is originating. But remember, the root cause cannot be determined in this manner.

The use of stethoscopes, sounding rods, and other listening devices can enable an experienced practitioner to detect such problems as rubs, bearing defects, cavitation, etc.

When listening to a machine try to determine if the sound is complex or simple, high frequency or low frequency, and from where the sound appears to be coming.

Effective audible inspection procedures include examination of the machine and surrounding area for the following:

- Sounds that are out of the ordinary
- Humming
- Squealing
- Growling
- Rubbing
- Cavitation
- Arcing/popping sounds
- Hunting/Beats
- Noise from leaks
- Comparison noise from bearings
- Water Hammer
- Lifting sentinels/relief valves
- Flow through system / components

Tactile Inspection

To hand feel a machine for excessive vibration, perform the steps below:

1. Start at the bearings, feeling in vertical, horizontal and axial directions.
2. Work downwards and outwards from the machine feeling the base, structures, pipes, pipe supports, valve stems, electrical boxes, electrical conduit, etc.
3. Try to get a sense of the frequency of the vibration, e.g., is it high frequency, such as a buzz or a tingle? Or is it low frequency, such as a shudder or a sway?

Figure 10. Motor Check

Other tactile observations should be performed as well. Effective tactile inspection procedures include examination of the machine and surrounding area for the following:

- Temperature comparisons on bearings
- Temperature comparisons on seal flush systems
- Temperature differences on cooler / heat exchanger inlet and outlet
- Temperature differences on filters / strainers inlet and outlet
- Feel oil for contaminants, and metal particles
- Feel for flow through systems / components
  Enhancing Visual Inspections
  Spot Radiometers
  Principles and Capabilities

Infrared Thermometers measure the amount of infrared energy emitted by a target object, and calculates the temperature of that object's surface. Typical features include laser sighting, adjustable emissivity, alarm functions, and trigger locks. Other features may include data loggers and graphic displays, thermocouples, and software interfaces.

It should be noted that the temperature reading is the outer surface temperature of the first surface the laser beam penetrates. If taking a reading through plexiglass or other transparent material that the laser penetrates, the temperature reading will represent the plexiglass surface only.

Figure 11. Spot Radiometer Limitations

Emissivity.

Emissivity is ability of a material to reflect heat. Different materials have different emissivity values and must be accounted for when attempting to obtain an absolute temperature reading. For comparison readings emissivity is less of an issue provided that the two target materials are the same. If there is a need for accurate absolute temperature measurement then the contact thermocouple provided should be used to cross check the infrared data. Your instrument has functions that allow you to select the correct emissivity value for the target material, but for the intent of this seminar and general instrument use, the "Free" setting will be used.

Measurement Spot Size.

The measured spot size depends on the distance between the object you are measuring and the infrared thermometer. This will vary depending on manufacturer and by models from the same manufacturer. Note that the temperature is an average of the temperatures contained within the spot circle. Move closer to the target to get a smaller measurement area.

Strobe Lights

Principles and Capabilities

Visual inspection of rotating assets in conjunction with using a strobe light allows other components to be evaluated.

- Coupling, shaft and key condition.
- Leak detection from bearing caps, mechanical seals and couplings.
- Mechanical looseness of machine components.
- Belt condition.
- Even tensioning / loading of belt drive systems

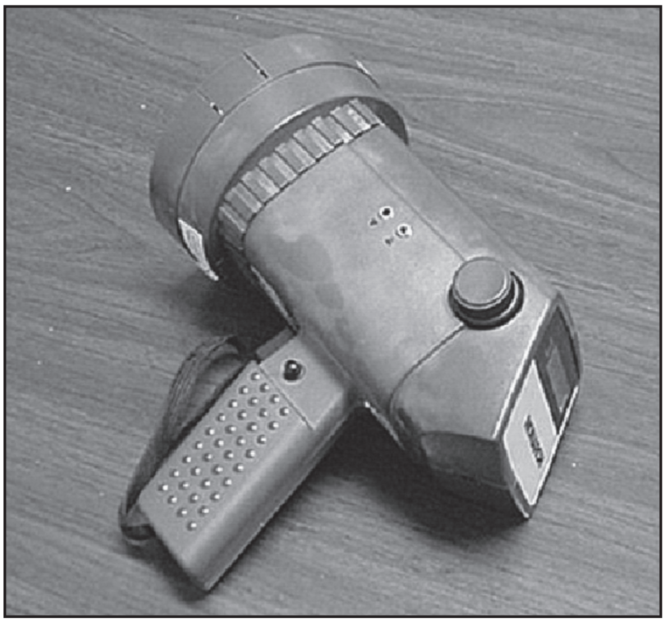

Figure 12. Strobe Light

Precautions and safety:

- Objects viewed with this product may appear to be stationary when in fact they are moving at high speeds. Always keep a safe distance from and do not touch the target. Be aware of others in the area and take responsibility for their safety by warning them of these precautions.
- Use of this equipment may induce an epileptic seizure with those prone to this type of attack.
- Do not allow liquids or metallic objects to enter the ventilation ports on the stroboscope to avoid damage to the instrument.
- Caution - there are lethal voltages present inside the instrument. Refer to manufacturer's literature for lamp replacement procedure before attempting to open the instrument.
- To assist in the inspection of couplings and belts with a strobe it is recommended to use expanded metal with a flat black finish for coupling and belt guards whenever possible. This permits the user to see through the guard with a minimum of reflection.

Summary

Performing visual, audible and tactile inspections can provide tremendous value when integrated into an overall reliability effort. Formalizing and documenting inspections that are being performed by non PdM technicians will allow data to be utilized by everyone. The acceptance of integrating technologies to gain a better picture of equipment condition is widely accepted. Why not use this same model to leverage information from personnel who traditionally are not viewed as having an active role in reliability? Many times operators and maintenance personnel can provide that "missing piece" of information that cannot be seen by the PdM technician when viewing equipment on a monthly or quarterly cycle. How many organizations would jump at the chance to add dozens of additional personnel to the reliability effort without adding additional cost? By training and engaging operators and maintenance personnel, that is exactly what is possible.

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Static and Dynamic Testing as Part of Predictive Maintenance Programs

by Timothy M. Thomas, Baker Instrument Co.

Abstract

Predictive Maintenance Programs, (PMPs), are becoming universally accepted as the best method for maintaining motor reliability within most modern plants and facilities. A complete PMP will include as many technologies as possible with each technology providing vital pieces to the diagnostic puzzle. Periodic static testing and more aggressive dynamic testing of motors are essential parts of predicting the potential for a motor to continue a safe and successful operation. Tracking and trending the results of electric motor testing, on a regular schedule is the most effective method of making intelligent predictions.

Introduction:

The Need for Motor Testing

The steady, safe and efficient operation of electric motors is essential to the productivity of all plants and facilities. Some facilities including hospitals, airports, major office buildings, and innumerable others have many critical and/or expensive motors. A motor failure could be catastrophic causing lost production and costly emergency repairs. For example, a motor failure at a nuclear plant can cost up to one million dollars a day for critical motors and may have a disastrous, long-lasting impact. Even failures at a waste water treatment facility can have a huge, negative environmental effect and can be very costly.

Motors fail due to numerous operational circumstances including power condition, mechanical influences and environmental hazards. According to recent *IEEE*[1] and *EPRI*[2] studies, at least thirty-five to forty-five percent of motor failures are electrically related. Monitoring the motors "electrical health" is, unquestionably, an important and vital consideration. Trending the historical operating condition of a motor makes early detection of any decline in the motors "health" possible. Planning "down time" and having only minor reconditioning repairs instead of a major rewind or replacement is far less expensive in both repair costs and lost production. Since electric motors begin deteriorating the instant they are started, it is necessary to monitor their operating condition on a routine, periodic schedule. Periodic monitoring and trending of data collected and properly diagnosed provides the technician with evidence needed to prepare for down time before a catastrophe occurs.

It is no longer practical to just "megger" a motor in order to determine its condition. Plants and facilities depend on a complete Predictive Maintenance Program (PMP) to monitor their operations and plan their repair schedules. A good predictive maintenance program requires both static (and off-line) and dynamic (or on-line) testing, with educated and trained technicians monitoring data routinely, with quality equipment. Besides voltages and currents, on-line test equipment must be able to capture and trend torque ripple and torque signatures as well as rotor bar side bands. Off-line testing with modern, high voltage test equipment is essential to getting reliable data. The voltages required to properly test motor windings cannot be reached with impedance based or low voltage test equipment.

On-Line Testing

Effective dynamic test equipment must be able to collect and trend all essential data that affects the operation of electric motors. Power condition including voltage level, voltage imbalance and harmonic distortions, current levels and current imbalances, load levels, torque signatures, rotor bar signatures, service factors and efficiencies should be tracked and trended. On-line testing is performed at the motors MCC, at the load side of a variable frequency drive or at an installed port, which allows for on-line testing without opening the MCC. Data is collected through a set of current transformers and corresponding voltage probes. The data collected, processed and analyzed provides the technician with an overall view of the normal operational environment to which the motor is subjected on a daily basis and of how the motor is responding within this environment. Often a motor is subjected to incoming power problems including low or high voltages, voltage imbalances and harmonic distortions. Lower voltages cause higher currents and therefore more heat. Higher voltages cause lower power factors and ultimately higher losses. A small amount of voltage imbalance creates an exponential amount of current imbalance which causes temperature increases. Harmonic distortion also causes thermal stress in motors. Any of these voltage problems can cause severe overheating in the motor even without factually reaching an over-load situation, and excessive heat is the insulation's major enemy. Some motors are subjected to physical obstacles that cause undue stress. Over greasing, misalignment and over-tightened belts all cause thermal stress.

Many motor failures can be traced to load related situations. Erratic torque signatures can be an indicator of load related problems. Broken or cracked rotor bars can also cause premature motor failures. On-line testing identifies these problems and routine trending will reveal the rate of decline. Of major importance to the overall health of a motor also is the "effective service factor." Two elements affect the service factor number: real operating power condition (voltage quality) and steady state load conditions. The effective service factor number represents the thermal stress caused by these two conditions on the motor. On-line testing can find and trend all these motor conditions.

Dynamic testing schedules should be tailored individually according to operating time, criticality, and any other important element of operation. Generally, an on-line test should be performed at least quarterly. Motors that begin to show obvious decline or thermal over-stressing should be monitored more closely until the motor can be statically tested or removed from operation and repaired. New and recently repaired motors should be tested as soon as they are returned to service in order to provide a historical record (or baseline) of their performance when the motor is at its "best."

Off-Line Testing

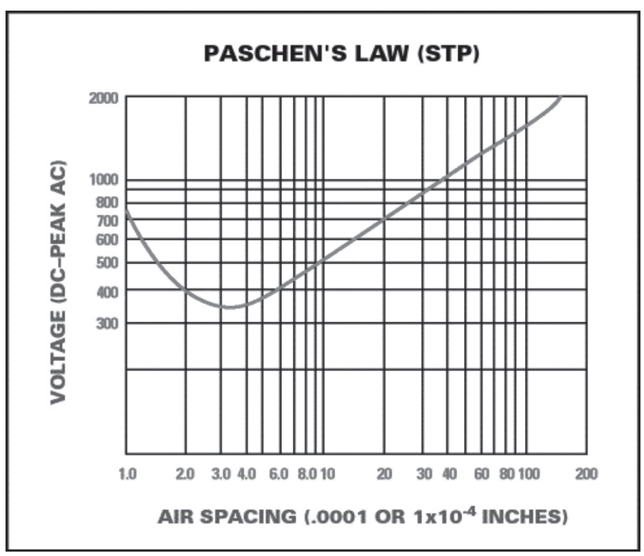
In general, motors are quite reliable and when properly maintained, one should expect at least one hundred thousand hours of continual operation. That is to say, a new motor operated within nameplate parameters should give us at least eleven years of steady use. Unfortunately, motors are almost always subjected to a variety of damaging elements with the end result being a rise in operating temperature. Thermal aging of the insulation is the major cause of insulation failure. Years of testing and numerous studies have shown that, as a "rule of thumb," "for every 10 degrees centigrade increase in temperature, the winding life is decreased in half."[3] Besides thermal problems, other causes of insulation failures include incoming line related problems. Spikes caused by lightning and surges created by switching and contactor closing contribute to insulation breakdown. Motors are also subjected to mechanical influences including bearing failure, environmental hazards and magnet wire damage caused during the manufacturing process. Even the physical movements of the windings during startups causes wear to the insulation system especially the magnet-wire insulation as D.E. Crawford has shown.[4]

Proper testing of all components of a motor requires a series of tests designed to emulate the conditions the motor will see in the field. It has been proven in numerous studies that low voltage testing, including capacitance, inductance, impedance, et cetera, are not effective tools in verifying insulation problems. Quality off-line test equipment will be able to perform winding resistance tests, insulation resistance tests, high potential (HiPot) tests, polarization index, and surge tests at IEEE, NEMA and EASA accepted standards. Top quality test equipment will automatically run a series of pre-programmed tests and provide a complete final report. This automatic equipment will stop testing before any damage is done to the windings.

The resistance test verifies the existence of dead shorts within the turn-to-turn coils and shows any imbalances between phases due to turn count differences, along with locating poor wire connections or contacts and finds open parallel coils.

DC insulation resistance testing detects faults in ground wall insulation or motors that have already failed to ground. Weak ground wall insulation (prior to copper-to-ground failure) can only be found successfully with the HiPot tests. The ground wall insulation system consists of the magnet wires insulation, slot liner insulation, wedges, varnish and often phase paper. DC HiPot test should be performed at twice line voltage plus 1000 volts since motors will see voltage spikes of at least that level during each startup. HiPot testing is necessary to verify winding suitability for continued service.

Surge testing detects faults in both inter-turn winding and phase-to-phase insulation systems. Turn-to-turn faults will not be seen by a megger or HiPot test. Potential faults can only be seen when the coils see more than 350 volts from turn-to-turn or coil-to-coil, as described by Paschen's Law.[5] The typical mechanism of fault progression is a turn-to-turn short causing excessive heat and progressing within seconds or minutes to



copper to ground faults. Faults are much more likely to occur between turn-to-turn winding coils due to the added stress caused by bending and exaggerated during the winding process. The ground wall insulation is generally many times stronger and more capable of withstanding voltage spikes and other stresses.

Conclusions

Integrating on-line and off-line testing into a Predictive Maintenance Program provides the technician with verification of his motor's condition (See case studies below). Both technologies are necessary in order to have a complete picture of a motor's health. Collecting both on-line and off-line data on a routine schedule allows for early warning of impending failures and opens the opportunity window for planned down time. Performing resistance, HiPot and surge testing along with dynamic testing provides the technician with a total picture of the motor's condition and allows him to track its rate of decline.

Modern test equipment includes enhanced and detailed reporting. Reports are easily generated, providing a written hard copy of test results and making diagnosing and comparing of data clearer and more accurate. Setting up and managing a program to monitor the motors within any facility is essential to insure the safe and continued operation and production of the facility. In most cases, a properly managed and operated Predictive Maintenance Program will save a plant or facility much more than it will cost to implement, administer and manage.

Case Studies

1) At a large waste water treatment facility in Florida, fourteen identical motors were scheduled for predictive maintenance. These motors were 40 horsepower aerators for a large treatment tank and operated continuously. Static tests were performed on all fourteen and each received passing marks on all tests. When dynamic testing was complete, it was noted that thirteen motors were acting very similar running within expected parameters at approximately 85% load, while the fourteenth motor was running at just over 30% load. Further inspection revealed a sheared coupling on the motor running at reduced load. The operators had no way of detecting the problem and the location of these motors made visual inspection difficult. The dynamic testing found a problem that was costing the customer both in wasted kilowatt usage and production.
2) Twelve 60 horsepower pump/motors were tested at a large office building. Six were chilled water pump/motors and six were condenser water circulating pump/motors. All twelve were installed at the same time and ran continuously. Dynamic testing was performed one day on all twelve and all appeared to be operating within expected parameters. The motors were shut down for a scheduled annual routine building maintenance and static testing was planned for the following morning. Resistance tests appeared normal on all, but two would not pass HiPot testing at the preset voltage. Three others failed the surge tests. The five motors were removed from service, disassembled and inspected. Two were found to be extremely dirty while three had no visual damage. All five were reconditioned, re-tested and replaced in service. The off-line testing prevented five potential catastrophic failures and allowed the customer to dictate the down-time.

Footnotes

1 Report of Large Motor Reliability Survey of Industrial and Commercial Installations,
Parts I and II, Motor Reliability Working Group, IEEE Transactions on Industry

2 Applications, Vol. IA-21, No. 4, pp 863-872, 1985.
"Improved Motors for Utility Applications," EPRI EL-4286, Vol. 1 & 2, 1763-1, Final
Report, October 1982.

3 D.E. Crawford "a mechanism of motor failures IEEE 1975"

4 D.E. Crawford "a mechanism of motor failures IEEE 1975"

5 Paschen's Law, F. Paschen 1889

Detecting Bearing Problems and Root Cause Bearing Failure Analysis

by Stuart Courtney, SKF Reliability Systems

The object of this paper is to develop the mindset of detecting and fixing problems and not just detecting failures. Often we see examples of totally wrecked bearings and alongside, the spectral and vibration data that detected the failure. To this end there must be a multi-stage approach: the vibration monitoring program must be used to detect the problem at the earliest opportunity, and the maintenance department must act on that (and that may not be to change the bearing, it may just be a lubrication problem). If the bearing is changed it is essential that it is changed at the right time. That is the key; if it is changed too early people say the system is flawed. If it is changed too late it may damage other components, and the evidence that can tell us what the problem was may be destroyed. The aim is to be Proactive and not Reactive.

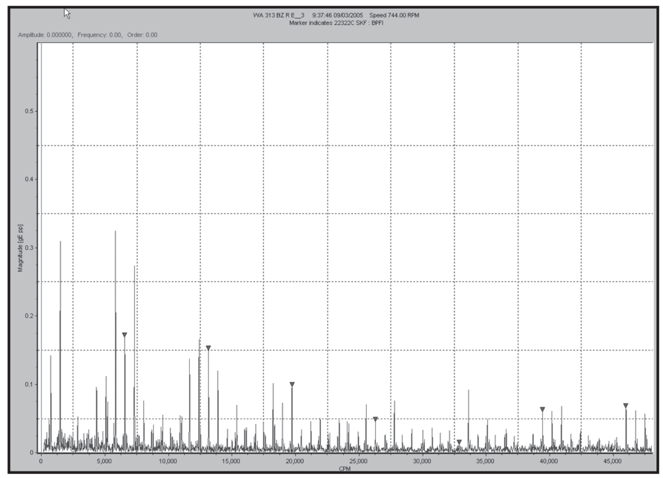
The decision-support system, SKF Bearing Inspector, is aimed at offering increased speed, consistency and higher quality in the bearing decision making process. It should help to prevent bearing damage or failure from recurring. As with any knowledge-based computer system, SKF Bearing Inspector gathers all the relevant information and experience available about rolling bearing damage – from basic principles to practical engineering results. Causal relations between symptoms and possible reasons do not exist in reality and can easily lead to wrong conclusions. This is simply because the reasons (e.g., wrong bearing mounting) result in the damage symptoms (e.g., signs of fretting), and not the other way around. A modeling of a relationship from causes to symptoms where uncertainty is attached to "possible failure states" fits much better with the physical phenomena that occur during bearing service life. With the aid of state-of-the-art computational intelligence techniques, this approach has been followed for the development of the program.

This paper will follow the ISO 15243;2004 as a reference.

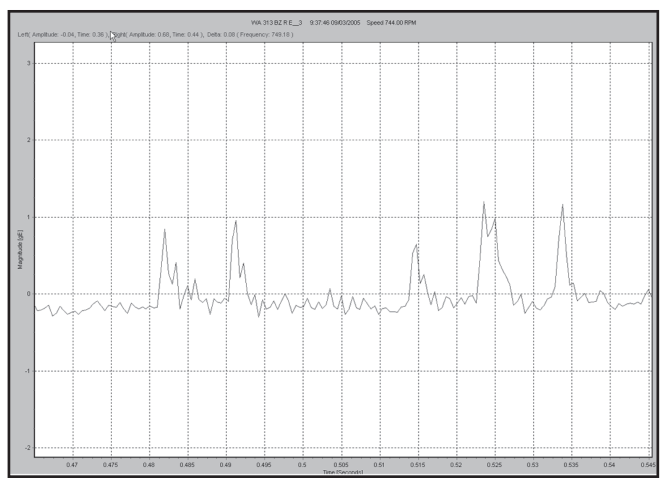
The problem

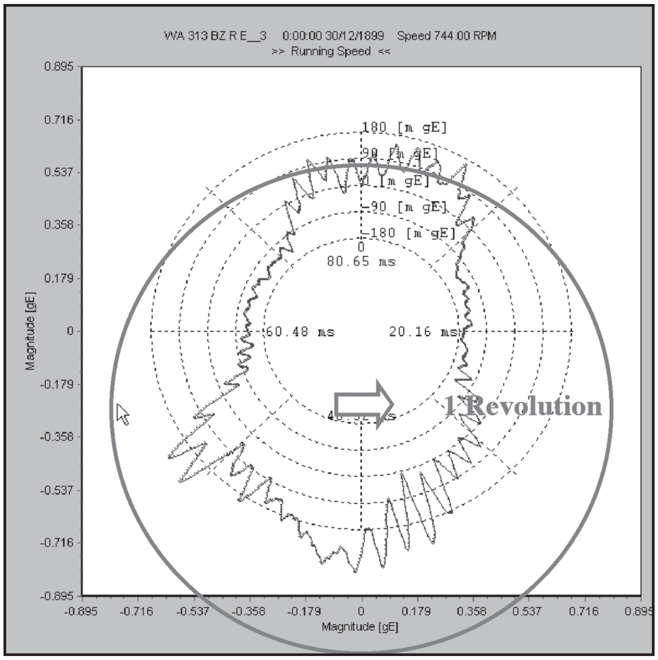
Condition Monitoring tools are often used as a way of detecting defects or failure patterns in rotating machinery. We often use condition monitoring tools to be predictive in our maintenance planning to subsequently be reactive in what we actually do. Before we can study how we can use the tools to prevent the failures we need to understand some of these buzzwords and look at what we need to do in order to use the collected data. There must also be a strategy for determining what to collect and how to turn the data into effective information. Take the case of this bearing: did we do a good job in detecting the problem or did we just detect failure? You could say we prevented a catastrophic failure of the machine, but what was the cause and can we prevent it happening again?

Enveloped Spectrum of the bearing



Waveform of the bearing





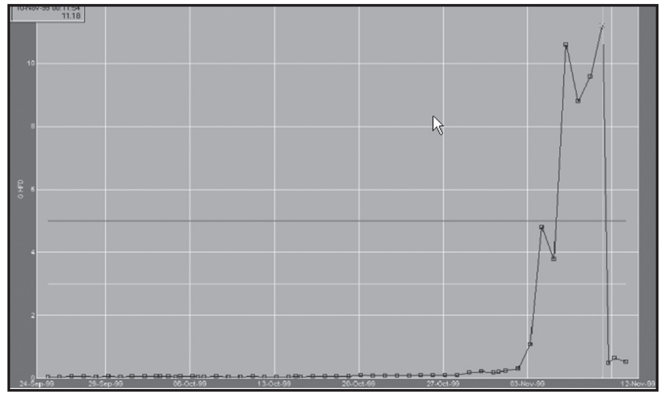
Cyclical Time analysis of the bearing

This bearing had failed a number of times, but all that was done was to change the bearing, which is a very expensive and time consuming job. By taking a time block of data it is possible to then join the ends to show the data in a profile plot. This time block represents one revolution of the bearing. The data is then Time Synchronous Averaged using a virtual trigger set by the time-length of 1 rpm. This data now clearly shows that there are two load zones in this bearing, and that will eventually lead to stress in the inner race and cage, and failure will occur. The journal was checked and found to be oval; it was then machined and the bearing correctly fitted. The bearing has been in service since and shows no sign of a problem. Root Cause Failure Analysis and Proactive maintenance worked. It is important to use these techniques before the functional failure occurs. The key is to troubleshoot the problem not the failure.

Lubrication

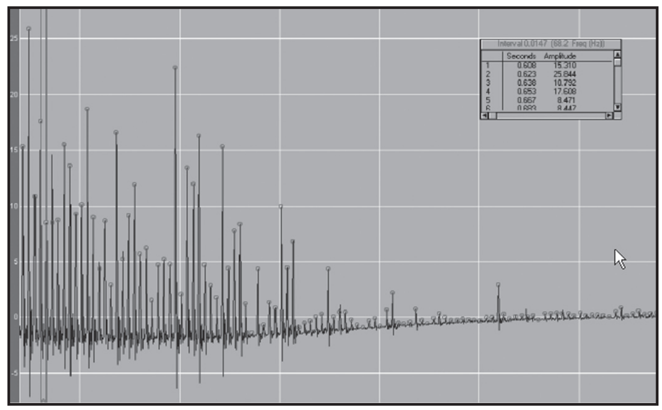
When the lubrication of a bearing starts to fail it generally causes an increase in vibration, noise or acoustic emission. A lubrication management regime is often based on listening to the bearing. This can work but, by far, the best way is to trend the data against engineering units.

The following trend shows what happened to a bearing when it was lubricated.



It can be seen that it apparently solved the problem but the level of vibration never returned to the level from before the problem. The increased level after lubrication was due to small particles of debris still in the grease.

The time waveform data was taken during the act of greasing the bearing. It can clearly be seen that the problem has been hidden by greasing.



Decision-support system for bearing failure mode analysis

Gaining insight and information from rolling bearing damage and failures is of strategic importance for SKF and its customers. The knowledge collected on bearing damage is accessible for SKF engineers as a web-enabled decision-support system called SKF Bearing Inspector. Allied with the knowledge of how bearing defect patterns appear in condition monitoring systems, root cause failure analysis can be greatly enhanced.

The decision-support system, SKF Bearing Inspector, is aimed at offering increased speed, consistency and higher quality in the bearing decision making process. It should help to prevent bearing damage or failure from reoccurring. As with any knowledge-based computer system, SKF Bearing Inspector gathers all the relevant information and experience available about rolling bearing damage – from basic principles to practical engineering results. Current knowledge-based systems have benefited from the experience of expert systems developed in the 1980s, although these suffered major flaws in aspects of reasoning capacity and computer power. These systems were often structured as decision trees that led from symptoms to possible causes. Causal relations between symptoms and possible reasons do not exist in reality and can easily lead to wrong conclusions. This is simply because the reasons (e.g., wrong bearing mounting) result in the damage symptoms (e.g., fretting signs), and not the other way around. A modeling of a relationship from causes to symptoms where uncertainty is attached to "possible failure states" fits much better with the physical phenomena that occur during bearing service life. With the aid of state-of-the-art computational intelligence techniques, this approach has been followed for the development of the program.

Knowledge system

Within a knowledge system, one generally distinguishes between modeling the knowledge with a certain knowledge representation and the reasoning principle, in order to derive problem-solving capacity. Regarding knowledge representation, several forms exist, such as:

Cases: Many bearing failure experiences can be found in case examples. Unfortunately, many practical cases are not well documented, and no uniformity regarding the documented parameters or failure mode conclusions exists. Example cases can, however, be used to model or verify other knowledge representations.

Rules: It is possible to generalize if-then rules between observed symptoms and possible causes. However, this is not appropriate because different causes can have similar effects that appear as similar symptoms.

Artificial Neural Networks: Mathematical relationships between symptoms and causes can be derived by using example failure cases. However, there are not sufficient numbers of discriminating cases to do this. Furthermore, system users require additional explanations rather than "black box" artificial neural network relationships that do not carry such explanations.

Probabilistic Networks: It is possible to derive visual networks in which nodes are connected by causal relationships, based on bearing failure theory and experience. Furthermore, probabilities are assigned indicating the weakness or strength of those relationships. By introducing correct causality from conditions to observations, this knowledge representation best fits the bearing failure diagnosis problem. Analysis of bearing damage and failure is principally a diagnostic task. Imagine a patient visiting his doctor with a specific complaint. The doctor first questions the patient about specific body and lifestyle parameters such as weight, smoking, etc. (conditions). Based on that information, the doctor makes hypotheses about likely diseases (failure modes). The doctor verifies or rejects these hypotheses through further questioning and inspection of the patient (symptoms). The process of a damage or failure analysis is similar to the doctor's approach. In a correct diagnosis, there are two reasoning steps:

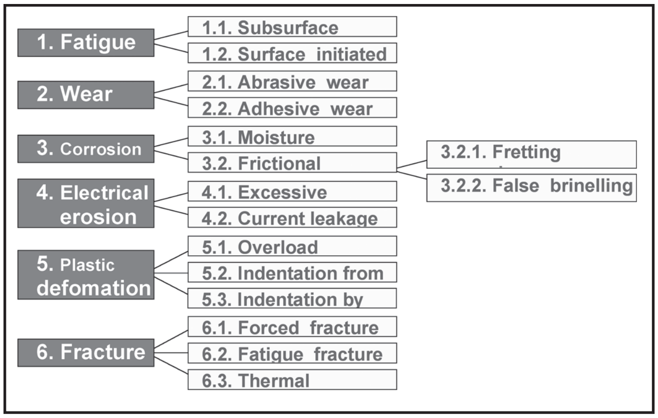
1. Hypotheses generation is where possible failure hypotheses are generated based on data. For example, the doctor starts asking questions to get an idea (hypothesis) of what could be wrong;

2. Verifying or rejecting hypotheses. One by one, the generated hypotheses are investigated and verified or rejected. For example, the doctor starts investigating the most probable diseases by conducting specific medical tests (blood pressure, heart rate, etc.).

With a probabilistic network, the two-step reasoning is implemented by forward and backward probability calculations.

Probabilistic network

The probabilistic network is a visual network in which nodes are connected by causal relationships, and probability calculations are applied. The network for bearing failure analysis has four node categories: conditions, internal mechanisms, failure modes and observed symptoms. Conditions represent the conditions from and under which the bearing operates. Examples are speeds, bearing type, load, temperature, installation details, environmental factors, etc. Internal mechanisms represent the physical phenomena that happen during operation, such as lubrication, film disruption, sliding contact, etc. Failure modes represent the types of failure, such as subsurface initiated fatigue and fretting corrosion. In Table 1, the various failure modes are listed. Observed symptoms represent the observable phenomena inside and outside the bearing, including discoloration, spalling, rust, etc. About 150 nodes are connected by causal relations between conditions of the bearing application, hidden mechanisms, physical failure modes and observed symptoms. In the modeling of the network, various sources of information were used. Apart from defining the nodes, the causal relations and probabilities, explanation texts (for each node) including examples and pictures are developed. In total, about 250 pictures have been included in the system.



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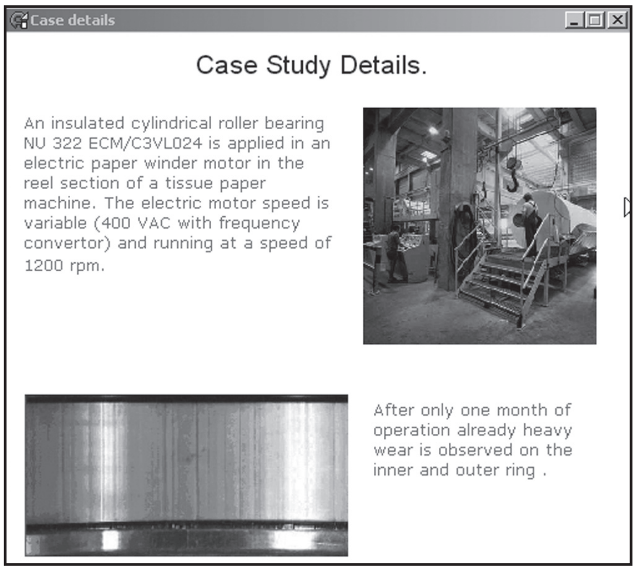
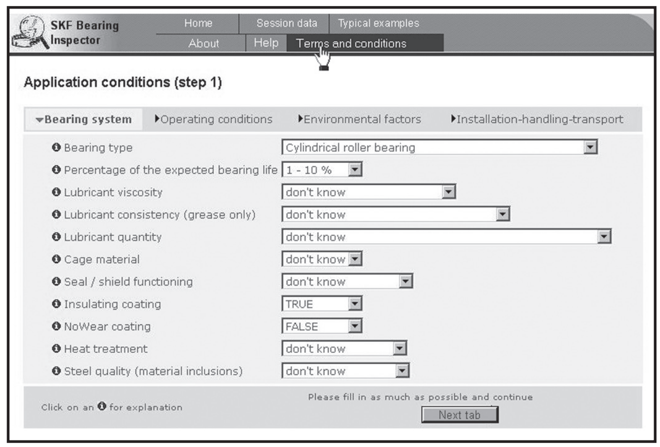
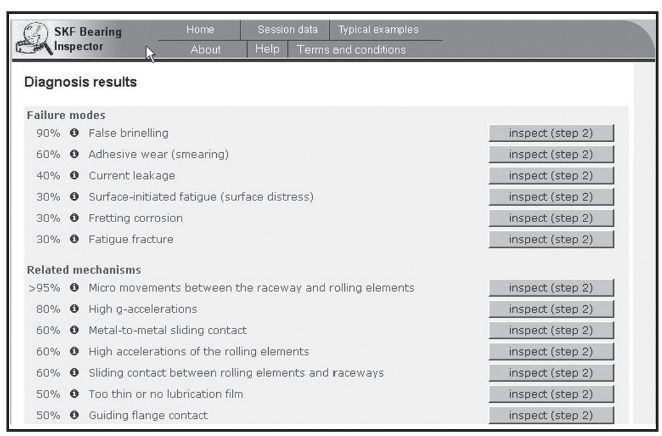


Case Study from Bearing Inspector

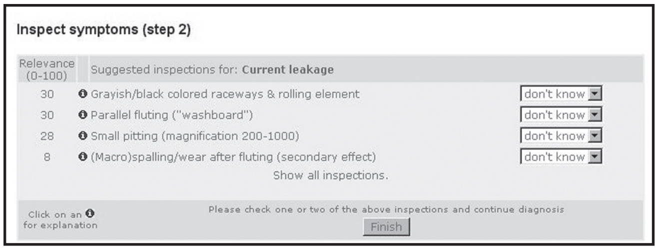
The Bearing Inspector contains several common bearing damage cases located under "Typical Cases." These can be used as training material to demonstrate how the Bearing Inspector supports the analysis of a bearing damage investigation. One example is of an electric motor in a paper mill. In this case, an electrically insulated cylindrical roller bearing NU 322 ECM/C3VL024 is used in an electric motor of a paper winder in the reel section of a tissue paper machine. The electric motor speed is variable (400 VAC with frequency converter) and running between 1000 and 1500 min-1. After only a month of operation, however, heavy wear was observed on the inner and outer rings. Loading the example case in SKF Bearing- Inspector sets all known application conditions (step 1). The first hypothesis of possible failure modes is calculated based on these application conditions. At this point in the analysis, Bearing Inspector gives a high likelihood of false brinelling, adhesive wear and current leakage. At first sight current leakage and false brinelling seem unlikely because the machine uses insulated bearings and all machines are properly supported with rubber pads. The user then has to perform the second step of the analysis by inspecting the bearing on failure symptoms. Clicking "inspect" results in a list of damage symptoms most relevant to the selected failure mode. The bearing is first inspected for false brinelling. Because no shallow depressions are found that can verify false brinelling, this failure mode is rejected. The analysis is continued with inspection of symptoms of adhesive wear. None of the symptoms related to adhesive wear are found either. Finally, by inspecting electrical current leakage symptoms, the presence of small pitting is found after magnification of the raceway surface. This verified the current leakage failure mode. Subsequently, the customer indeed discovered an earthing problem in the winder construction causing the electrical current leakage.



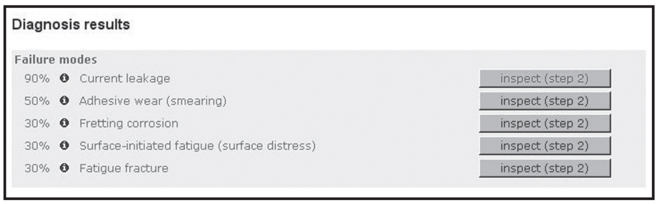
Example step 1: Application conditions are filled by loading the electric motor winder data among other bearing type, coating, speeds, etc. Detailed information and examples are provided under the information button.



Example step 2: Bearing Inspector gives its initial diagnosis based on the information so far, the confidence factors are included.



Example step 3: Inspection on symptoms for current leakage failure mode. After inspection and enlargement of the runway surface, small pitting is confirmed. Several examples are provided under the information button.



Example: Final diagnosis: results based on the provided application conditions (step 1) and bearing system inspections (step 2).Both the probabilities of the most relevant failure modes and related internal mechanisms are listed. The results can be printed out as MS Word or HTML report.

Instead of investigating all possible observations and non-filled-in conditions, the most relevant ones are suggested, dependent upon the failure hypothesis (or internal mechanisms) that need to be investigated. In other words, these are the application conditions or observations that have the most discriminating effect on the failure hypothesis. The discriminating effect is determined by a mathematical measure.

For all possible not-filled-in conditions or observations, this measure is scaled between 0 and 100. An example is given in the illustrations. Eventually, by investigating the application conditions and observations, the likelihood of the failure hypotheses and internal mechanisms is determined and ranked. These then form the conclusions of the bearing damage analysis. The system is further extended with various functions that can help the user. A simple file with user instructions is provided for getting started. Session data control is available for session data storage and retrieval. Also, in a file marked "Typical Examples," users can be guided through the application of the program. For convenience, an extensive report can be generated in MS Word or HTML format, including the relevant conditions, observations and failure mode probabilities.

Conclusions

Bearing Inspector meets the need for a fast, more consistent, high-quality decision making process for bearing damage and failure investigations. This web-enabled system is available for SKF engineers to support customers in bearing damage and failure investigations. It can help to determine how a bearing failed and therefore how to ensure that the same failure cannot happen again. These failure patterns should then be used to determine how to configure a vibration based condition monitoring program.

Reliability Testing Methods and Acceptance Criteria for Industrial Equipment

by Christopher Smith, The Goodyear Tire & Rubber Co.

INTRODUCTION

An important part of any manufacturing operation is the procurement and installation of new equipment. Having a methodology to apply statistically based testing requirements for new equipment is a fair an unbiased way to assess the initial performance of equipment. Successfully meeting the acceptance criteria should also lead to a more efficient start up when the equipment is installed. In many instances no standard exists; acceptance criteria for each type of machine vary by the engineering and or purchasing group involved.

It would be advantageous to have standardized formats and requirements for the testing of production equipment. This does not mean that the acceptance criteria of each piece of equipment would be identical. It does mean that the acceptance criteria of each piece of equipment would be created utilizing the same methodology, and the acceptance report for any given machine would have the same look and feel. Having a standardized methodology and format will make it much easier for corporate and plant engineers as well as management to understand the initial reliability and production capability of a piece of equipment.

Having well-defined and quantifiable goals for equipment reliability should make specification writing easier. This will be an advantage when dealing with vendors. Having a standard methodology for specifying reliability criteria will facilitate the creation of the specifications so that they can be included in the request for a quote. Including this information gives vendors an understanding of what is expected of the design. If the testing methods, data collection methods, and "pass/fail" criteria are included in the request for a quote there won't be any surprises for the vendor when the equipment is tested. This should alleviate some of the problems related to unclear or misunderstood expectations. Also if the standards are not met it is clear that the vendor will be responsible for any upgrades or re-engineering necessary to achieve the acceptance criteria.

RELIABILITY TESTING METHODOLOGY

There are four categories that should be considered when defining acceptance criteria for equipment. These categories are reliability of the machine and the product quality before the machine is shipped, and the reliability of the machine and the product quality after the machine is installed in the production facility. This paper will only focus on the acceptance criteria related to the reliability of the machine. Criteria related to product quality will be discussed in a separate paper.

It is first necessary to calculate the amount of machine downtime that is acceptable. This should consider needed throughput, machine production rate, production speed losses, quality losses, and scheduled nonproductive time. Once the amount of acceptable unplanned downtime is determined it is necessary to determine the average downtime per breakdown that the machine is likely to experience. This value will almost always be an educated guess that includes technician response time, troubleshooting time, time to obtain replacement parts, and repair time. The facility that will receive the new equipment should be consulted to determine reasonable estimates for response time, troubleshooting time, and time to obtain parts. The equipment manufacturer usually can offer some assistance in determining the average time of repair. Some caution should be exercised here. The estimates of average repair time given by the vendor are likely to reflect repair times based on repairs being performed by experienced technicians. Even though it is likely that the plant technicians will not be proficient on a new piece of equipment right away, this is the value that should be used in the calculation because the calculation should reflect likely, steady-state conditions of the machine.

After the acceptable amount of downtime and the average downtime expected per occurrence has been determined these values can be used to calculate the MTBF (Mean Time Between Failure) goal for the equipment. The MTBF goal can be calculated by dividing the acceptable downtime by the estimated average downtime per occurrence and multiplying this by the base time period of the acceptable downtime. The base time period is defined as the denominator of the units of the acceptable downtime. For example if 60 minutes per day of downtime is acceptable then the base time period would be 1440 minutes (1 day).

The following calculation can be used to determine the time necessary to test the equipment to ensure that the minimum level of uptime is achieved or the maximum level of downtime is not exceeded at a certain confidence level. The confidence level is the probability that the sample of data used to calculate the test duration accurately represents the true distribution of the entire population. For example if the confidence level is .90 then it could be stated with 90% certainty (or confidence) that the sample data and consequently any calculations performed using the sample data would accurately represent the entire data population. The data population for our case would be the measured MTBF over the useful life of the equipment. When selecting a confidence level, the higher the level selected the more likely that the sample population accurately represents the entire population. Consequently the higher the confidence level that is selected the longer the test period will need to be. The confidence level chosen should reflect the criticality of the equipment to the operation. As a rule of thumb a confidence level of 90% is used for general equipment and for critical equipment level of a 95% or higher.

The following is the formula to determine the test duration that demonstrates that the MTBF will be at least a target value ( ) at the designated confidence level under the condition that when the equipment is tested no failures occur during the test period.

$$T_a = \frac{m_g}{2\text{X}^2_{\alpha:2}}$$

T_a - Total time of the test

m_g - MTBF goal

X^2 - Value of the chi squared distribution at the alpha significance level and 2 degrees of freedom.

α - Significance level is equal to 1 minus the desired confidence level

If a failure does happen during the test, the original test period does not have to be finished and a second test of equal duration started. A new value for the length of the test given a number of observed failures can be calculated and the test can be allowed to continue after the proper repairs have been made.

$$T_a = \frac{m_g}{2\text{X}^2_{\alpha:2r+2}} \qquad 1$$

r – Observed number of failures during the test duration.

There is an important discussion that should be presented concerning "proper repair."

At the occurrence of any failure observed within the test, the test should be suspended and a root cause failure analysis performed. When the root cause has been identified it must be properly addressed before the repair is performed and the test resumed. This means that the failure time, number of total cycles experienced by the failed part, and root cause should be documented. Then the root cause of the problem should be solved including any hardware or software re-engineering or installation procedure changes. After the solution to the failure has been implemented and documented the test duration should be recalculated and the test should resume.

This test is focused on the machine reliability not the process reliability; therefore, is does not require that stock be processed by the equipment during the test period unless processing the stock causes significant stress to the equipment. If the stock processing does cause significantly increased stress to the machine then the test should be conducted with stock being processed by the machine or that stress simulated if possible. Process reliability is also an important consideration but will not be addressed in this paper. When using this calculation to determine a test period for a piece of equipment the confidence level chosen should be the confidence level that is required for long term operation.

An example of this calculation will now be presented.

The required uptime determined from the throughput requirements is 95%. This will be defined as 72 minutes of downtime per 1440 minute day. A confidence level of .95 is chosen because this machine if fairly important to the production of the plant. (Note: the required uptime does not have to be calculated in units of time. It could also be calculated in cycles.)

T_a = the total time of the test

α = 0.05

m_g = 1440 – 72

m_g = 1368 minutes

$$T_a = \frac{m_G \text{X}^2_{\alpha:2}}{2}$$

$$T_a = \frac{1440 * \text{X}^2_{0.05:2}}{2}$$

$$T_a = \frac{1440 * 5.9915}{2}$$

T_a = 313.9 minutes or 2.99 days

This equation shows that to demonstrate an MTBF of one day or 1440 minutes the equipment must be tested for 4313.9 minutes or just under 3 days of continuous testing without a failure. If there are one or more failures observed during the test then the following calculation applies for total test time to demonstrate the above criteria with r failures.

$$T_a = \frac{m_g \mathrm{X}^2_{\alpha:2r+2}}{2}$$

r = Number of failures

If the test period must be shorter than the prescribed test period due to superceding constraints then the minimum MTBF that can be expected based on the amount of actual test time can be determined by solving the above equation for and setting equal to the actual test time. If the constraint is schedule or budget related using this method to calculate the difference in the MTBF that can be substantiated by a shortened test period and the MTBF confirmed by running the test for the full period can be used to help justify the additional test time required to substantiate the desired MTBF.

The methodology previously described could be used to perform a comprehensive short term evaluation of the equipment reliability at the manufacturer's site prior to approving the shipment of the equipment. Due to the invasiveness of the disassembly, shipping, and reassembly process this testing should be conducted again after installation of the equipment in the plant. This will serve as verification that the machine is in the same condition after installation that it was before it was shipped. The testing process can also become a part of the requirements for release of the equipment to production.

In addition to calculating the test time necessary to substantiate an MTBF there are some additional considerations that should be addressed before the testing process begins. For brevity these are listed and not discussed in detail.

1. Agree with the vendor about what constitutes a failure.
2. Agree how failures will be recorded.
    a. Will this be an automatic system or a manual one?
    b. What format will be used for the failure information?
3. Agree on which party will conduct any needed RCAs .
4. Agree on the process for resolving any RCAs.
5. Determine who will conduct the testing: vendor associates, customer associates, or a combination.
    a. Many times it's best to have the vendor's associates conduct the test and have a customer representative observing the test.
6. Determine the schedule for the testing.
    a. Testing should be done in conditions similar to real production conditions. Determine if testing will be done 24 hrs/day or if it will have to follow another shift schedule.
7. Ensure that the machine will have all of the necessary utilities available while the test is in progress.
    a. Understand what planned maintenance might be conducted in the facility while the test is scheduled. Sometimes planned maintenance on another piece of equipment will necessitate a utility outage. For instance planned maintenance might be scheduled for the compressor supplying compressed air to the machine being tested.
8. Determine responsibility for obtaining and disposing of any stock necessary for the test.
9. Agree on what constitutes success of the test and who will sign off on a successful test from both the customer and the manufacturer.

AFTER INSTALLATION PLANT ACCEPTANCE CRITERIA

After the machine is installed at the facility and initial checkouts have been satisfactorily performed the machine should be subjected to the same testing process as outlined for equipment reliability in the first part of this paper. After the equipment has satisfactorily passed the test the equipment is ready to be placed into "probationary production."

The probationary production period is meant to accomplish two goals. The first goal is to provide a longer term equipment reliability testing period. The second goal is to ensure manufacturer participation in the proving of their machine. The probationary production period should consist of 30 - 90 days of plant production. During this period the following should take place:

1. All machine failures should be recorded and specific standardized information gathered.

For the purposes of the probationary period, machine failure is defined as any time that the machine is not performing as designed or intended. During the probationary period it is as important to document the process failures as it is to document the hardware or software failures. When process failures are noted the following information should be collected: a) time and date of failure, b) type of failure (It may be advantageous if predetermined list of failure types is prepared before the probationary period starts, to facilitate documentation while the machine is producing), c) cause of failure, d) all stock and machine conditions that could contribute to the failure should be documented .

2. Failure information on all failed hardware should be collected.

The following should be gathered from any failures of machine components: a) time and date of failure, b) model / manufacturer's part number, c) serial number, d) storeroom identification number, e) production machine number in which the component was installed, f) description of failure and preliminary root cause failure reason.

When a failed part is replaced the same information that is collected and recorded about the failed part should also be recorded for the new part installed. The data collected on the newly installed part should be entered into a database so that when that part fails accurate life information can be determined. This will provide solid information on which to base inventory levels and will provide the data needed to statistically analyze the failure rate of this particular type of part to determine if redesign is needed.

3. All failed hardware should be shipped back to the equipment manufacturer (not the component manufacturer).

Under normal operating conditions this is not the most effective method for returning parts to be repaired or replaced. However this is necessary during the probationary period so that the equipment manufacturer can perform a failure analysis. This will allow the equipment manufacturer to make a determination if there is redesign that needs to be completed, installation procedures that need to be changed, or other methods employable to avoid the failure in the future. During the period that the equipment manufacturer is conducting the failure analysis one of the customer's engineers should be in close contact with the equipment manufacturer to ensure that the failure analysis conclusion and resolution plan meet the customer's satisfaction.

4. The equipment manufacturer shall perform a failure analysis, supply reason for failure, and action plan to mitigate future failure to plant and corporate engineering contacts.

5. If failure analysis determines that there is an equipment design problem the manufacturer is responsible to make the design enhancement and supply parts to the customer for equipment upgrade. If skill level, equipment required to install upgrade exceeds plant capability, or the plant prefers then manufacturer will also provide the labor to install.

In this way plant labor and resources will not unnecessarily be consumed for design or installation enhancements for which the equipment manufacturer should be responsible.

6. Time to failure data should be analyzed using the Weibull distribution as outlined below.

The Weibull distribution is a very flexible distribution and one that is well suited to describing the failure rate of equipment3. Below is a brief introduction of the Weibull distribution and how it can be used for calculating equipment failure rate.

Failure data must be collected in either cycles to failure or time to failure. Once this data has been collected, 30 days worth of data for the probation case, it should be entered into a table and ordered from smallest to largest. An additional column should be added to the table that will contain the median ranks for the failures. The median rank values should then be entered into this column. Median rank values are the true value that the failure probability should have at a 50% confidence level. These values can be obtained from the Reliability & Life Testing Handbook Vol. 1 4 Appendix A. The total number of failures recorded in the probationary period (N) should be used to locate the correct table in Appendix A. Then the values of the 50% column of that table should be entered into the column in the table being created. The median rank failure probability and the times or cycles to failure should be plotted on Weibull plotting paper. A best fit line should then be drawn through the points plotted. A parallel line should then be drawn from the 62.3% failure probability scale (y axis). This line will cross a scale at the top of the plotting paper. The point at which the line crosses the scale is the value of the β parameter of the Weibull distribution. If the value of $\beta > 1$ then the equipment is exhibiting wear out type failure, if $\beta = 1$ then the equipment is exhibiting useful life characteristics, if $\beta < 1$ the equipment is exhibiting early failure. An acceptable β value should be determined and used to evaluate the data from the probationary period. A value between .8 and 1.5 can be used as a rule of thumb.

7. The effective throughput (including quality losses, speed losses, machine downtime, and scheduled outages) of the machine should be tracked. This should be compared to the design throughput requirement that was established to calculate the machine test time.

8. After successful completion of the probationary period (meeting β, effective throughput, and proper response to machine failure) authorized plant personnel should sign off on the equipment and the manufacturer should receive the final payment for the machine.

   In the event that the equipment does not meet the success criteria of the probationary period the probationary period must be repeated until all of the criteria for success are satisfied. When the success criteria have been met and signed off by the engineer responsible and the responsible individual(s) at the plant the machine is considered in regular production and can be supported by the plant going forward.

SUMMARY

The use of reliability testing of industrial equipment should expose weaknesses of design and manufacture before installation of equipment in the field. It should also shorten the start up period of new equipment. Having formalized plant reliability acceptance criteria should complement current acceptance criteria and help to ensure that installed machinery will function at the level required to support production.

APPENDIX A

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Improving Asset Performance by Changing Weibull Shapes

by Bill Keeter, Allied Reliability

Introduction

The Weibull distribution is a widely recognized statistical distribution created by Swedish born Waloddi Weibull to describe life distributions. The primary advantage of the distribution is that it requires very small amounts of data when compared with other forms of statistical analysis. It could be said that the primary job of physical asset managers is to prevent failures. Stated another way, the primary job of physical asset managers is to prevent data points for failure analysis. A statistical method that is effective using small amounts of data is a very useful tool for understanding equipment failures.

Equipment fails based on its basic design and on how it reacts to the way it is operated and maintained. This relationship means there is a direct relationship between maintenance and operating activities and the Weibull shapes that are present in plant equipment. In this article, we discuss basic Weibull shapes, how operating and maintenance activities impact them, and the steps organizations can take to change those shapes to meet the needs of the business for equipment availability.

The Bathtub Curve

The bathtub curve consists of three distinct regions. Each region contains its own unique values for the Weibull parameters, Eta, Beta, and Gamma (Definitions in Table 1). The Weibull parameters provide insight into the failure mechanism that is present.

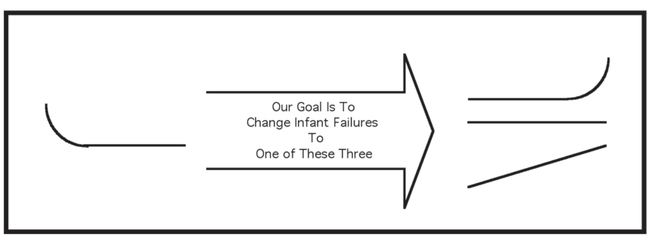

Figure 1. The Bathtub Curve with Weibull Parameters.

Weibull Parameter	Description
Gamma (γ) or Location Parameter	Gives the location of each section of the Weibull curve. Gamma 3 is particularly important for items with a wearout mechanism because it marks the beginning of the zone of increasing failure rate.
Beta (β) or Shape Factor	Beta values are an indicator of the failure behavior of the component. Beta values less than one represent infant failures, Beta values equal to one represent random failures, and Beta values greater than one represent wearout failures.
Eta (η) or Characteristic Life	Eta gives an estimate of how long components might last after being put into service. It represents the point in time where 63.2% of the components in service are likely to have failed.

Table 1. Weibull Parameter Definitions.

What Do Beta Values Tell Us?

Beta values are extremely important because they tell us the failure behavior of the component. Knowledge of the failure behavior will lead us down a certain path when trying to improve overall reliability and availability.

Infant Failures

Beta less than one, or infant failure, indicates that there may be a quality issue present among our maintenance, operating, or spare parts acquisition programs. There is no time based maintenance activity we can do for these types of failures until we determine the root cause or causes of the infant failures. Our goal is to eliminate or minimize the high early failure rate represented by the curve.

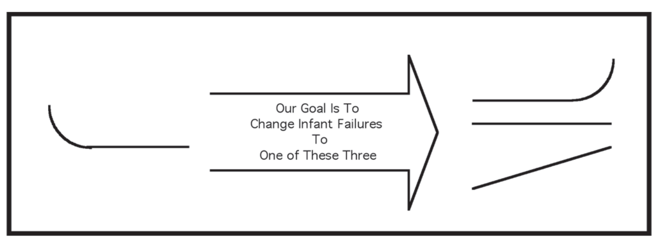

Figure 2. Changing Infant Failures to Random or Wearout.

There is a large laundry list of possible causes of infant failure mechanisms. Table 2 gives some examples of the potential sources of infant failures.

Source	Causes
Maintenance Activities	• None or inadequate quality of work control procedures and policies • Unskilled or untrained maintainers • None or poorly written maintenance procedures • Poor organizational communication • No focus on precision maintenance • Inadequate maintenance supervision
Operating Activities	• None or inadequate operating procedures, especially start up procedures • Unskilled or untrained operators • Inadequate operations supervision
Procurement Activities	• Procurement focused solely on price • None or inadequate quality control procedures for incoming spares, especially custom manufactured parts from third party vendors • Parts procured from a wide variety of vendors

Table 2. Potential Organizational Causes for Infant Failures.

High Failure Rate Random Failures

Random failures are characterized by a Beta value of approximately one. High failure rate random failures have a shorter than expected, or shorter than desired characteristic life, or Eta. Random failures typically lend themselves to either route based, or constant condition monitoring, but still may have a greater than desired negative impact on the goals of the organization if the failure rate is too high.

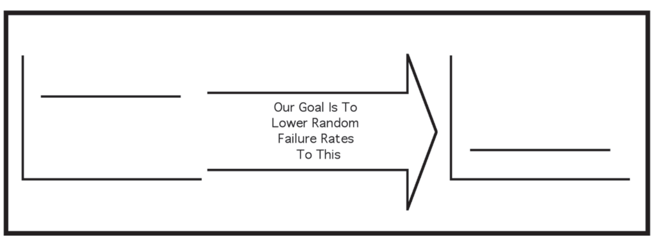

Figure 3. Reducing Random Failure Rates.

Random failures are usually caused by some outside action that induces failures into the component. The organizational activities listed in Table 3 are some likely sources of higher than expected or desired random failure rates.

Source	Causes
Maintenance Activities	• Inconsistent torque applied to bolts • Poor maintenance cleanliness practices • Inadequate lightning protection • Lubrication routes not well designed
Operating Activities	• Equipment occasionally operated outside its design envelope • Process upsets created by inadequate quality control of incoming raw materials • Process upsets created by unskilled or untrained operators
Procurement Activities	• Parts procured from a wide variety of vendors • Parts specifications not clear

Table 3. Potential Organizational Causes for High Random Failure Rates.

Short Life Wearout Failures (Early Wearout)

Generally, wearout failures lend themselves to some sort of time based replacement or overhaul strategy. Wearout, even though it is predictable, can have a significant negative impact on the goals of the organization if components are not lasting as long as they are expected or desired to last.

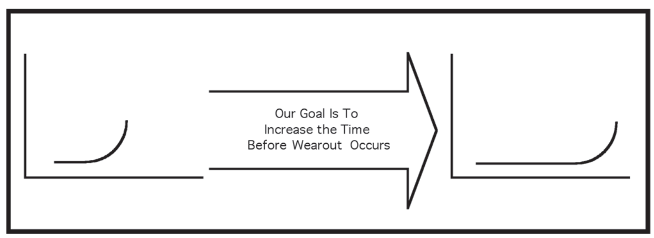

Figure 4. Extending the Wearout Curve.

Early wearout is often caused by a lack of understanding of the stresses present in the equipment during the design phase, but there are organizational activities that can lead to early component wearout as shown in Table 4.

Source	Causes

Maintenance Activities	• Under-lubrication of bearings
	• Using incorrect lubricant for the service
	• Over-lubrication of bearings
	• Service intervals too long for:
	    • Lubrication
	    • Adjustments
	• Consistent over tightening of belts
	• Consistent over torquing of bolts
	• Using parts below required specifications

Operating Activities	• Consistently operating the equipment outside its design envelope
Procurement Activities	• Purchasing spares below needed specifications

Table 4. Potential Organizational Causes for Early Wearout.

How Do I Know What I Have? (How to Build My Weibull Shapes With No Data)

Many companies do not have the necessary data to complete Weibull analysis on their failing components. They do have experienced personnel in maintenance and operations who are knowledgeable about what fails and how it fails. The trick to building the Weibull shapes without data is to learn what questions to ask the maintainers and operators as show in Table 5.

Question	Answer	What The Answer Tells Us
1. How many times have you repaired this particular failure in the last three years?	A number	The answer gives an approximation of the mean time between failures or the characteristic life. It may not be exact, but it will be close enough for making a reasonable decision.
2. If you work on it today, do you know you have to warn others that you worked on it because it may not get through until day after tomorrow?	Yes	There is probably an infant failure mechanism present. You will need to do some Root Cause Analysis (RCA) to determine why and eliminate the cause.
3. If you work on it today, do you know you won't have to come back to work on it again until sometime near the mean time to failure you determined in Question 1? If you wait too long after that will it probably fail?	Yes	This is probably a wearout failure. It can most likely be addressed with a time based replacement or overhaul strategy, but RCA should be performed to find root cause if the wearout is occurring sooner than desired.
4. If you work on it today, is it likely to fail sometime between now and the mean time to failure determined in Question 1, but you can't be certain that it will last that long?	Yes	This is most likely a random failure. It can be handled by condition monitoring unless the failure rate is higher than is tolerable for the organization. If the rate is too high, then Root Cause Failure Analysis (RCFA) should be performed to find and eliminate the cause.

Table 5. Some Simple Questions for Determining Weibull Failure Mechanisms.

Changing the Failure Mechanisms

Changing failure mechanisms requires effort on multiple levels. At the outset, the immediate causes of the failures must be addressed so that repetition of the failure does not occur. Eventually the organizational or latent causes need to be removed in order to insure that the conditions originally allowing the failure mechanisms to be present are removed.

Table 6. see next page

This Is the Starting Point

The questioning method for building Weibull shapes gives you a good starting point in the absence of hard data, but it is not a perfect replacement for hard data. Hard data along with analysis of the impact or effects of the failures will allow you to sharpen maintenance tactics and strategies to move you closer to achieving your business goals.

The key things to remember are that the failure mechanisms present in your equipment are a reflection of the maintenance, operating, and procurement activities present within your organization, and that there is a direct link between best maintenance and operating practices and changing the Weibull behavior of your equipment.

Reference, About the Author

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Bill joined Allied Reliability in 2006 after serving as President of BK Reliability Engineers, Inc. where he provided training and facilitation services to help facilities improve asset performance using Weibull Analysis, Reliability Centered Maintenance, Availability Simulation, and Life Cycle Cost Analysis. Bill is has over 25 years of experience in Maintenance Engineering and Management. He has successfully implemented maintenance improvement programs in a variety of manufacturing and production facilities.

Action	Benefits	Cautions
Root Cause Failure Analysis (RCFA) or Causal Analysis	• Will uncover the physical, human, and latent roots of the failures • Will help lower or remove the infant failures so that an effective maintenance tactic can be developed	RCFA must be viewed and managed as a program, not as a thing to do. There must be well defined policies and procedures that are followed to insure that the right things are analyzed, and that recommendations that will further the organization's goals are implemented in a timely fashion.
Establish a Maintenance Quality Control (QC) Program	• Will help insure that maintainers are focused on quality and workmanship, and that controls are in place to help insure the quality of completed work • Will help eliminate repeat work • Will help lower or remove the infant failures so that an effective maintenance tactic can be developed	The QC program has to establish guidelines for what constitutes good quality, and contain sufficient auditing to insure that the program is carried out. First line supervision must be made aware of the importance of their role in insuring the quality of maintenance work. The QC program should be developed by a team consisting of craft, supervision, and management to help get maximum buy-in for the program.
Establish a Training Program for Maintainers and Operators	• Will help insure that the maintainers and operators understand the best operating and maintaining practices, and that they understand the impact of their behaviors on equipment failures • Will help lower or remove the infant failures so that an effective maintenance tactic can be developed • Will help lower the failure rate for some random failures	Great care must be taken to insure that the program addresses the competencies required, and the level of skill required in each competency. The use of competency maps is highly recommended to insure that the right people get the right level of training for the least amount of resources expended. There may be some immediate training that will eliminate a particular failure, but the overall program will require vision and a focus on future results.
Establish Written Procedures for Maintaining Equipment	• Will help insure that maintenance jobs have repeatability, and that there is some consistency in job quality • Will help lower or remove the infant failures so that an effective maintenance tactic can be developed	The written procedures must contain enough information to complete jobs properly without insulting the intelligence of the craftspeople. Procedures are best developed by a team consisting of craftspeople, planners, and procurement specialists. There must be an established audit process to insure that the procedures are kept up-to-date.
Establish Written Procedures for Operating Equipment	• Will help insure that equipment is operated within a set range of parameters, and that equipment shutdown and startup is accomplished in a way that minimizes negative impact on equipment reliability • Will help lower or remove the infant failures so that an effective maintenance tactic can be developed	The written procedures must insure that both new and seasoned operators have enough information available to operate the equipment as desired. They are best developed by a team consisting of maintainers and operators so that the implications of operating the equipment in a certain way are well understood.
Establish a Quality Control (QC) Program for Spares Procurement	• Will help insure that procured spares meet at least the minimum specifications required to establish the desired level of equipment reliability • Will help lower or remove the infant failures so that an effective maintenance tactic can be developed	The spares QC program is best developed by a team consisting of maintainers and procurement specialists. It is important to make sure that those responsible for procuring parts understand the full implications of their purchasing decisions. There must be established quality criteria for parts manufactured by third party vendors, especially machined parts. It is important to perform quality inspections on the incoming parts to insure they meet engineering specifications.
Establish a Lubricant Management Program	• Will help insure that the correct lubricant is applied in the correct amount at the correct point at the correct interval and that it is clean • Will help lower the failure rate for some random failures • Will provide life extension for some early wear-out failures	Establishing a Lubricant Management Program is not a simple task. It is not enough to simply establish lubrication routes. In most cases extensive training is required to insure good results.

Table 6. Actions You Can Take to Change Your Weibull Shapes.

Bill's experience includes maintenance leadership positions in the US Military, the nuclear industry, chemicals, paper converting, and plastic film manufacturing. He has provided training and reliability consulting services to petroleum, process, mining, and defense industries in the United States, Mid-East, and Europe. Bill has developed competency maps for Reliability, Availability, and Maintainability Engineering for the Petroleum Industry's PetroSkills® program.

Bill is a Certified Maintenance and Reliability Professional with the Society for Maintenance and Reliability Professionals Certifying Organization. He also holds degrees in Business Administration and Electrical Engineering.

Asset Basic Care from a TPM / Six Sigma Perspective

by Steve Reilly, Design Maintenance Systems Inc.

Introduction

Asset Basic Care programs use operations, maintenance and/or lubrication staff to physically inspect and verify the operating condition of work areas, processes, and fixed / mobile assets. Some of the topics that will be covered in this paper include:

- What is Asset Basic Care?
- How can Asset Basic Care programs be implemented?
- Automated Asset Basic Care programs – an alternative to paper-based inspection methods.
- Tools and technology for automated Asset Basic Care.
- Review the key elements to ensure a successful Asset Basic Care implementation.

The goal of this paper is to show that an asset basic care program can be an effective foundation to preventive and predictive maintenance program. Asset basic care can also make a profound contribution to any organization implementing a Six Sigma quality strategy. Most importantly, basic care can have a significant positive effect on asset availability, as well as reduce operations and maintenance expenditures in the achievement of increased asset reliability.

What Is Asset Basic Care?

Asset Basic Care is a commitment by the operations and maintenance staff within a plant to ensure that assets maintain their expected level of quality and volume for output, while reaching their expected lifespan within the plant.

Asset Basic Care attempts to greatly reduce or eliminate reactive maintenance by implementing procedures to ensure that assets are

- Properly configured with all specified guards, safety devices and environmental protection,
- Checked that they are within proper operating parameters (i.e. acceptable temperature / pressure / flow rate, etc.),
- Protected from dirt, water and other sources of contamination,
- Checked for seals operating properly (no leaks of lubricant or process fluids), and
- Scheduled so that the correct type and amount of lubricant is used.

These checks are all carried out in a thorough asset care regimen. The investigative part of this regimen also attempts to catch incipient problems by monitoring assets for both visual (qualitative) and measurable (quantitative) indications of change.

Along with the inspection processes of the program, an Asset Basic Care process focuses on education of the operators, the lubrication staff and the maintenance/reliability staff. Asset Basic Care puts high emphasis on both operator-managed inspection programs and lubrication management efforts.

Asset Bare Care forms the foundation layer of an overall integrated Total Plant Reliability strategy and can also be a key component in the development of a sustainable Six Sigma approach to maintenance.

Origins of Asset Basic Care

Inspection rounds have always been a part of the maintenance process. Having operations and/or maintenance staff go to the plant floor, the garage or the engine room and check belts, fittings, seals, fluid levels, etc. in an informal manner has been carried out since the Industrial Revolution.

The more structured approach of scheduled, defined and documented inspection rounds was one of the fundamental concepts that came to be known as "Planned Maintenance." Developed during the years of the Second World War, planned maintenance methods were applied as a means of assuring high levels of machinery availability. Over the rest of the 20th century, planned maintenance and its numerous offshoots have been applied in all industry types in Europe and North America.

At the same time, Japanese industry, faced with considerable challenges, developed a variant of planned maintenance now known as Total Productive Maintenance (TPM). As with planned maintenance, frequent inspections are a fundamental tenet of the TPM process, with a heavy emphasis on the involvement of the equipment operators in the inspection process. Asset Basic Care is derived from several of the concepts ("pillars") of Total Productive Maintenance (TPM). Some of these concepts are:

- 5S Program, making problems visible by organizing the work area.
- Autonomous Maintenance, which involves both operations and maintenance in caring for assets at the source.
- Continuous Improvement Programs.
- Safety, Health and Environmental Inspection and Improvement.
- Team Based Approach to Identifying and Resolving Issues Concerning Asset Availability.

The following quote from Kunio Shirose, a conceptual TPM author, focuses on the element of TPM that is the basis for the Asset Basic Care approach:

"A very important aspect of TPM is the establishment of autonomous maintenance. The purpose of autonomous maintenance is to teach operators how to maintain their equipment by performing:

- Daily checks
- Lubrication
- Replacement of parts
- Repairs
- Precision checks
- Early detection of abnormal conditions

As with most of the Lean Manufacturing techniques and tools, autonomous maintenance is based on education and training. It is about raising awareness of the operators on the knowledge and understanding of the operation principles of their machines." Kunio Shirose, TPM Consultant .

Inspection processes can therefore be operations-driven or maintenance-driven; often they are a combination of both departments. The management of an inspection program is just as likely to be under the control of operations / production as maintenance.

Asset Basic Care and Six Sigma Programs

A Six Sigma systemic quality program provides businesses with the tools to improve the capability of their business processes. Six Sigma can be defined as a disciplined, data-driven approach and methodology for eliminating defects in a wide variety of processes, which includes all forms of manufacturing and process industries. A key element of Six Sigma programs is "kaizen," the Japanese process of continuous improvement using a variety of problem-solving and analysis techniques.

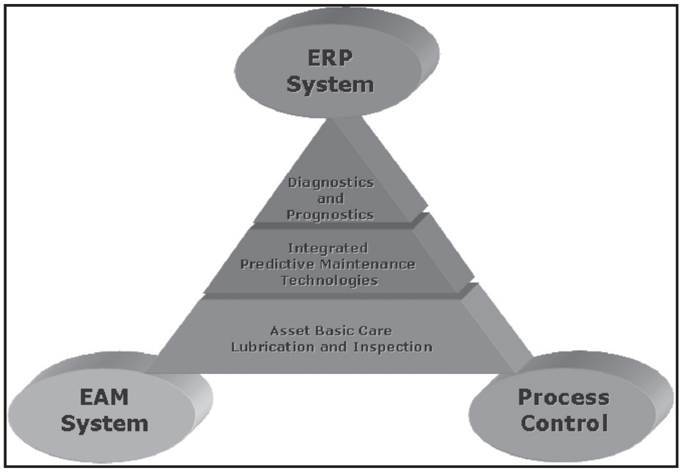
One of the fundamentals of the Six Sigma approach is the requirement for data. Data sets are used to determine the original state of a process, the current state of that process, the rate of improvement and the proximity of the process to the desired quality levels. Asset Basic Care, with its emphasis on frequent and rigorously scheduled inspections, produces a steady stream of both quantified and qualified evaluations of assets, systems and processes. The data collected by these inspections, plus the data generated to measure the compliance to the Asset Basic Care inspection schedule itself, can be used effectively to generate metrics for any Six Sigma program. A well-run Asset Basic Care program is not only a catalyst for improvement in and of itself, it can also be one of the primary data-gathering tools to evaluate the effectiveness of all continuous improvement procedures within the plant.

Asset Basic Care in the Overall Reliability Strategy

Asset Basic Care fits in as a foundational element of a plant's Total Plant Reliability strategy. A Total Plant Reliability strategy details the availability and contribution of a plant's resources to be used in asset inspection, condition monitoring, planning and scheduling and logistics for the creation of a reliability program. The strategy provides for optimal use of organizational resources with sufficient asset availability to meet the organization's output requirements.

A Total Plant Reliability effort uses the skill sets available within the organization (and through the judicious use of external expertise) to generate improvements in the following areas:

- Improve planning and scheduling by increasing the effectiveness of the EAM/ERP systems for maintenance management.
- Reduce or eliminate reactive maintenance by optimizing use of early warning technologies such as asset inspections and predictive maintenance technologies.
- Enable the organization to develop and achieve a targeted mix of run-to-failure / preventive / predictive maintenance work orders.
- Fine tune work execution, by ensuring that job plan estimates are accurate and complete, and match actual work order resource expenditures with a minimum of variance. Optimize spare parts inventory management.



Overall Reliability Strategy

Successful Total Plant Reliability programs are built upon the foundation of **Asset Basic Care**. The use of tools such as predictive maintenance, diagnostic systems and reliability centered maintenance / maintenance optimization can all be made more effective when they are used on assets that are clean, properly sealed, operated within correct operating parameters, properly lubricated and frequently monitored for visual changes.

Integrated Predictive Maintenance Technologies - brings multiple technological disciplines together to evaluate asset health. Vibration analysis, lubricant analysis, thermography, and ultrasonic analysis are all powerful technologies, the results of which can be made more effective when used in conjunction with an Asset Basic Care program.

Early indications of failure using predictive maintenance tools are much more evident in assets that are clean, well-operated and properly lubricated. Also, the elimination of evident problems through Asset Basic Care makes predictive maintenance processes more attuned to detection of less evident faults.

Diagnostics / Knowledge Retention - can utilize all of your basic care, predictive maintenance, reliability audit and maintenance cost data together to help automate diagnostic evaluation about the condition of assets. Asset Basic Care programs are a prime source of operator and maintainer knowledge that can be embedded in a diagnostic system.

Maintenance Program Optimization – the data collected through an Asset Basic Care program is invaluable when engaged in a maintenance optimization / RCM analysis, especially if the basic care data is paired with failure history data taken from the EAM system. If the EAM system is capable of work order initiation based on condition, basic care findings can be used to enable work scheduling based on assessed asset reliability.

Systems Integration with other plant systems **(process control / CMMS / EAM / ERP) –** basic care data can be delivered to ERP systems and EAM systems for maintenance purposes, but the most common delivery process is to process data historians. Distributing the findings throughout the plant can be very helpful in focusing the attention of all plant personnel on the reliability, safety and environmental metrics collected by an Asset Basic Care system.

It is therefore evident that Asset Basic Care is a solid foundation for a successful overall reliability program.

- Early indications of failure using predictive maintenance tools are more evident in assets that are clean, well-operated and properly lubricated.
- Daily or per shift inspection data is always available to the reliability team for immediate analysis verification.
- Reliability specialists can focus on complex reliability issues rather than simple operation or lubrication conditions – these conditions are detected by operations or lubrication techs.
- Plant-wide distribution of Asset Basic Care system findings can focus attention on the overall reliability of the plant (through the development and use of key performance indicators).

Benefits of Asset Basic Care

Asset Basic Care programs have been implemented in hundreds of organizations, both in process and discrete manufacturing facilities. Benefits of a successfully implemented care regimen include:

- Reduced unplanned downtime / reactive maintenance work.
- Reduced corrective maintenance cost per repair.
- Positive long-term impact on safety and environmental performance.
- Improved employee morale through cooperation between maintenance and operations.

Some benefits that have been documented by organizations that have implemented Asset Basic Care programs include:

Paper Mill, Florida - An Asset Basic Care program at a paper mill in Florida resulted in a 70% reduction in reactive repairs in three years and a reduction in maintenance budget by one-third.

Paper Mill, Virginia - An Asset Basic Care program at a paper mill in Virginia was credited as a major contributor to a 20% increase in total mill production – even with the permanent shutdown of one of mill's six paper machines.

Carbon Black Plant, Louisiana - An Asset Basic Care program at a plant in Louisiana led to a 32% reduction in ongoing preventive maintenance work orders, and a 10% reduction in annual maintenance costs.

Implementing Asset Basic Care

An Asset Basic Care program can be implemented as a separate program in and of itself, or as part of one or more broader programs. Implementation of basic care programs can differ considerably, depending on the type of organization, industry, and especially on the goals and objectives of the team within the organization that is spearheading the program. The main success factors are clear assignment of roles, effective management support, appreciation of cultural issues, and having a clearly laid out implementation process for all participants to follow.

Role Assignment / Management Support

During the development and initial roll-out of an Asset Basic Care program, the necessity for upper management support and clear, unambiguous role assignments cannot be overstressed. A successful basic care program requires a high level of cooperation from operations staff and maintenance staff, and this cooperation can best be managed with managerial support from the higher levels of both (or above both, preferably).

Either the individual who has been put in charge of the roll-out of the basic care program should be directly involved with the initial deployment area, or he/she should have a liaison who is directly involved with the area. One strategy that has been utilized is the formation of a "Reliability Group" which is comprised of individuals from both the maintenance and operations staff.

Cultural Issues

All of the elements of 5S, see below, are appropriate for a basic care program. The most important, and the one that has the most profound effect on the work place, is self-discipline, sometimes referred to as sustain, or sustainability. The concept that all personnel in a plant are responsible for the assets within the plant is as much a cultural change as it is a technical or procedural change.

Sort	Remove unnecessary items from the workplace	"When in doubt, throw it out"
Straighten	Locate everything at the point of use	"A place for everything, and everything in its place"
Sweep	Clean and eliminate the sources of filth	"The best cleaning is to not need cleaning"
Standardize	Make routine tasks standard operating procedure – what to do and when to do it.	"See and recognize what needs to be done"
Self-discipline	Sustain by making 5S second nature	"Understand what needs to be done without being told"

A culture of self-discipline is one of the key factors that will determine if a basic care program will thrive, or simply be seen as another management program du jour.

At a pulp and paper mill in Louisiana in early 2004, operators initially resisted the implementation of a basic care program. By June 2005, the basic care program was credited with a $30 per ton reduction in maintenance costs, this at a time when paper mills have been shutting down due to high operating costs and oversupply. Plant personnel achieved this by embracing the basic care concept and the culture of self-discipline that it implies.

Implementation Steps

The implementation of an Asset Basic Care program involves the following steps:

1. Design Inspection Forms
2. Operator Training
3. Inspection Scheduling / Optimal Route Length
4. Develop Feedback Mechanisms
5. Execute Asset Basic Care Cycle
6. Measure Performance

Step One: Design Inspection Forms

Properly designed inspection forms have the twin goals of ease-of-interpretation and fast completion.

- **Easy To Read -** Design the inspection forms (or data capture screens) with as simple a language level as possible.
- **Consistent -** Make inspection questions as consistent as possible for each asset type, so the operator can complete the inspection as quickly as possible.
- **Non-Ambiguous -** Design the questions (data entry fields) so that it is clear which exception item is to be selected/entered if a fault is detected.

Inspections can involve anywhere from two to ten points per asset/machine train, depending on the complexity of the inspection item. Typical inspection items include:

- Check lists, single and multiple check-off.
- Operating Hours, Usage Meters.
- Predefined and Ad Hoc Notes.
- Fluid (lubricant, fuel, coolant etc.) levels.
- Process Parameters (pressure, flow, draw …).
- Temperature / Sound / Ultrasonic levels.
- Vibration (velocity and shock pulse) levels.
- Images / Sketches.

Step Two: Operator Training

Operations staff is the main resource for implementing an Asset Basic Care program. The primary key to success is operator training.

- **Choose Appropriate Inspections -** It is important to train the operators to carry out inspections at an appropriate level of complexity.

  From IDCON "As a guideline-if an operator can be trained in an inspection method in less than 15 minutes, he or she should be trained to do that inspection." The corollary to this statement is that if the inspection requires more than 15 minutes to teach an operator, it may not be a suitable candidate for inclusion in a basic care program.

- **Explain WHY as much as WHAT and HOW -** Operator buy-in is essential for a successful inspection program, and a training program should emphasize the reasons why the program is being implemented. It has been our experience that there is a direct correlation between the level of effort expended to give the operators understanding about the reasoning behind an inspection process and the level of buy-in.

- **Train The Trainers -** Designate and train one or more employees of the plant staff (reliability, operations, IT) as the program trainer. This is especially important if one-time training of the operators is being carried out by external consultants. The operators will be much more comfortable carrying out the inspection if there is a backup resource readily available.

- **Plant-Floor Training -** All operators should be walked through their inspection rounds at least once, preferably more often, during the initial training program.

- **Tools Training -** If the inspection program is to be implemented using automated tools, then training must be extended to include the software systems and handheld data collection tools. However, it is important not to let the tools training become the primary focus of the training effort – tools are merely the tail, the inspection process itself is the dog.

Step Three: Inspection Scheduling / Optimal Route Length

A) Developing Data Collection Procedures

Essential to Asset Basic Care are the data collection procedures needed to detect problems and measure improvement. These include:

- Operator Asset Production Check Sheets.
- Operator Area Housekeeping Check Sheets.
- Lubrication Routes.
- Asset Condition Check Routes.
- Safety / Health Protection Inspection Routes.

B) Inspection Rounds

Determining the best way to execute a program of inspection rounds (either operator-based inspections or lubrication inspections) raises a number of questions, but two questions are always raised.

How often should inspections be carried out?

In theory, inspection frequency should be based on the known length of time between a failure indication and the failure event itself - the potential failure to functional failure, or P-F interval.

In reality, we usually don't know these failure intervals. Also, the inspection process is not solely concerned with failure – we are also interested in finding out operating states that are sub-optimal from a performance or even an esthetic perspective, The amount of failure or fault data needed to derive accurate (or at least statistically valid) failure intervals can often be very hard to come by. When we ARE able to derive statistically valid inspection intervals, they are often at odds with the practicalities of the plant operation.

Fortunately, we have found that very good estimates of optimal inspection frequency usually come from the operators and reliability staff within the plant itself. Also fortunately, it is appropriate to derive inspection intervals from established practice.

In plants where operators are already carrying out once-per-shift or once-per-day inspections, it can save a lot of time to simply review and optimize the existing inspection frequencies. Within 4-6 months of implementing a basic care program, there is usually enough data collected to be able to review and alter the inspection frequency. Route frequency review should be built in as part of the Asset Basic Care inspection cycle.

How long should an inspection route take?

Route length can vary considerably from plant to plant.

It is our experience is that expected completion time for routes should be no longer than two hours. For once-per-shift or once-per-day routes, it is usually impractical to have routes that take longer than an hour – the norm for these types of routes is 20-30 minutes.

Longer routes generally have poorer data collection compliance statistics, as they often cannot be completed within a single shift.

Step Four: Feedback

Proper feedback requires a method (or methods) to deliver usable information to maintenance, operations and management.

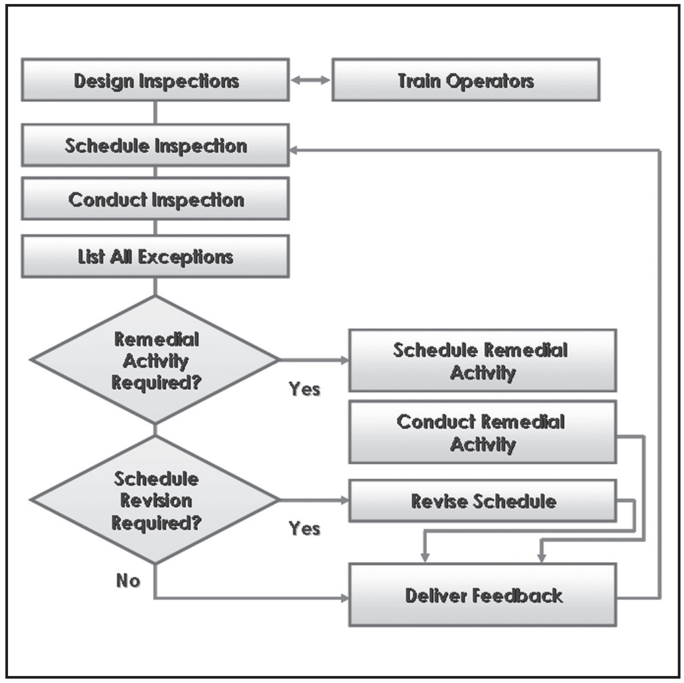
- **Reports -** It is important to sit down with the operators while the basic care program is being designed, to understand just what information the operators want to see in their basic care reports.

Often, operators want reports that contain the same data as the reports received by maintenance, but formatted and ordered in different ways.

- **Plant Data Display Systems -** If operations is heavily invested in existing data display systems such as Honeywell PHD, OSISoft PI or AspenTech IP.21, consider delivering inspection data via these systems.

Reporting inspection results to operations through a known system can increase operator acceptance of the process.

- **Compliance Metrics –** compliance reports or KPIs are becoming a standard part of basic care inspection programs. These tools measure how closely the inspection process is matching up to the prescribed schedule. Good compliance metrics enable decision-makers within the plant or organization to use basic care data with confidence, to make effective production or maintenance decisions.



Step Five & Six: Asset Basic Care Cycle

Asset Basic Care Cycle

The execution of an Asset Basic Care program involves the following steps:

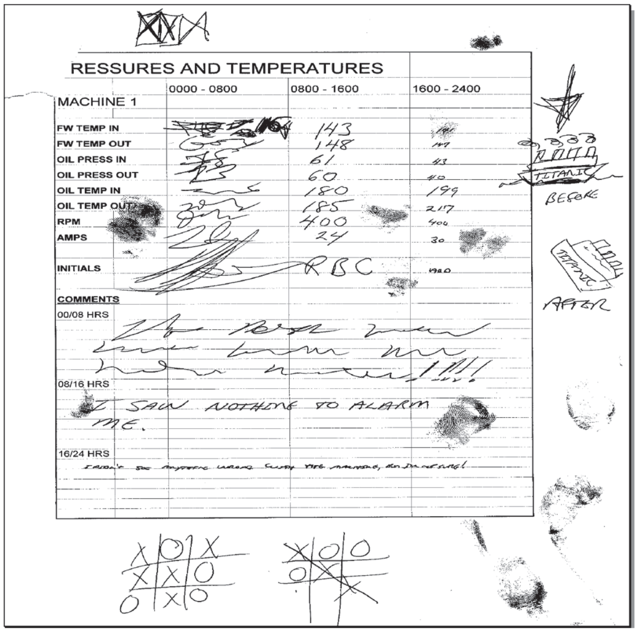
- Schedule the inspections for a time period.
- Carry out the inspections in a timely manner.
- Generate and deliver a list of noted exceptions.
- Notify all participants about any exceptions found during the inspections.
- Schedule and conduct any remedial action needed to eliminate the exceptions.

Automated Asset Basic Care

Challenges to Manual Inspection Procedures

There are a number of challenges to manual inspection process. Inspection programs using check sheets are difficult to monitor – many inspection rounds never get carried out, and it's difficult to determine if they haven't been carried out.

The data collected on inspection check sheets is highly prone to error – entries are illegible, different inspectors use their own terms to describe problem conditions, meter values are transcribed incorrectly. This is difficult for the person reviewing the inspection results, and even more difficult if those results are required to be entered into a database or a spreadsheet.



An Unfortunate Example of a Paper Check Sheet

Another source of error is simply that there is often confusion about which machine train is being inspected – especially in process industries where there is a lot of identical equipment in operation.

The inspection check sheet offers little additional support to the inspector when he/she discovers what may be a problem – there isn't any way to review previous inspections or query the check sheet for further help.

Often, reporting of immediate problems is done verbally. This not only leads to inadequate traceability of the problem (its cause, etc.) but the verbal reporting process can cause many problems to be under-reported, as the inspector will inevitably concentrate on the current most serious problems and not report those that are looming, but not currently critical.

Finally, the inspection check sheets need to be reviewed by someone capable of taking the next step – either ordering work to be done or more tests.

Automating the Inspection Procedures

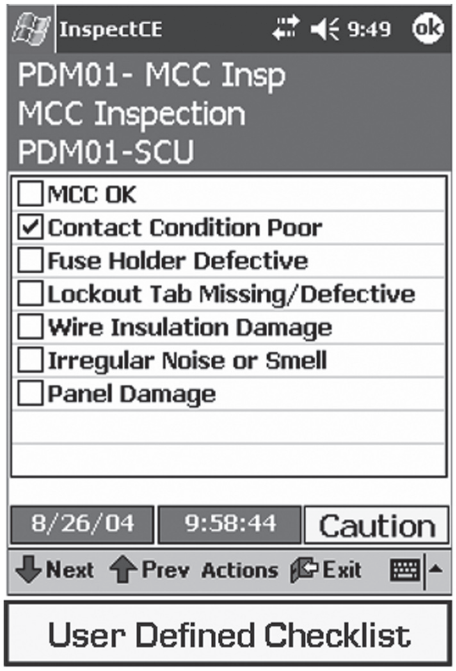
There is no question that Asset Basic Care inspection procedures can be carried out using paper check-sheets. However, after having installed automated Asset Basic Care programs in over 100 plants worldwide, we can say with assurance that automating the program offers several advantages.

- Implementing Asset Basic Care programs is easier and more efficient.
- It increases the accuracy and consistency of collected data.
- Immediate feedback is available to the operators when assessing the asset.
- Exceptions are indicated immediately to maintenance and reliability staff.

Tools for Automating the Basic Care Inspection Process

When the system is electronic, it is easy for an inspector to check on the last reported condition of an asset and check up on any repair carried out since the last inspection. Checking on the integrity of completed repairs adds significantly to the quality of the organization's repair process.

Well-documented and highly compliant data allow an easy comparison of results from one inspection to the next. Machinery and process parameters, when logged, can be analyzed to establish trends in equipment performance to provide an early indication of the presence of a developing fault condition.



Example of Electronic Check Sheet Item on Pocket PC

Conclusion - Keys to Success

Management elements that need to be addressed to ensure a successful Asset Basic Care program:

- **Role Assignment –** assigning responsibility for the program.
- **Housekeeping –** building a culture of self-discipline in the workplace.
- **Training –**operators need to fully understand what problems they are to detect and the tools they are expected to use.
- **Management Support –** both operations and maintenance management must "buy-in" to the program.

Technical elements that need to be addressed to ensure a successful Asset Basic Care program:

- Design of Asset Inspection Methods that clearly define what problems the operators are looking for.
- Developing Route Paths for optimal data collection efficiency and 100% data capture.
- Developing Route Schedules to ensure timely and accurate data collection.
- **Measuring Data Collection Compliance –** "what gets measured, gets done."

The keys to a successful Asset Basic Care data collection program can be summarized as – you need to be SURE.

- **Simplicity.** The process of collecting data must be simple to learn and remember.
- **Understanding.** Operators must understand (be trained) what to look for when carrying out an inspection.
- **Reliability.** If the data collection process is unreliable, or causes "paper pile-up," the system will be considered more trouble than it's worth.
- **Effectiveness.** Operators must see positive results from their inspection efforts – feedback at all stages is critical for the program to be considered effective.

Getting the Most Out of Your CMMS/EAM System

by Dave Loesch and Stephen Slade, Oracle

Note: The following is intended to outline general product direction. It is intended for information purposes only, and may not be incorporated into any contract. It is not a commitment to deliver any material, code, or functionality and should not be relied upon in making purchasing decisions. The development, release, and timing of any features or functionality described for Oracle's products remains at the sole discretion of Oracle.

Summary: Many firms today are not leveraging the full capacity of their current Computerized Maintenance Management Systems (CMMS)/Enterprise Asset Management (EAM) Systems. Analyst studies indicate that as little as 5-10% of current CMMS/EAM capabilities are used in many cases with medium use factor in the 20-30% level. It is the exceptional firm that exceeds 40% of the capability and benefits available from a fully implemented CMMS/EAM to them. But why is this the case?

This paper explores the current trends taking place within CMMS/EAM with a look at both the present and future trends emerging. Many firms, quite frankly, have not kept abreast of the many features and functions available to them or have operated in an isolated world.

World of Change

We must first acknowledge that we are living and working in a dynamic world. Things are moving around us continuously whether we realize it or not. It is perfectly natural to attempt to hold the world still as we write new code or add some element of functionality in the perfect operating world. Acknowledging change is the first step; having the necessary support and service systems in place to accommodate those variations is the second. Changes often take place slowly, like the introductions of steam power over sail or the railroads over the horse and wagon. It took over 20 years for the car and truck to become commercially viable 100 years ago. Many firms continue to hang onto their "tried-and-true" manual and paper based record systems simply because it was the way "we always do things around here." Case in point is today's doctors office, governed by stringent HIPPA regulations, or real estate closings, still requiring a mountain of paper with numerous signatures. Between 22 and 25% of healthcare expenses are consumed by administrative paperwork. So we agree that as the world turns, some systems have an improved adoption over other delivery mechanisms. An example of rapid uptake may be the newest iPod, sold to every available teenager by the millions at Christmastime, with capability to download hundreds of songs and a variety of videos,

We live in an Integrated World

As the planet gets smaller with direct connection, we can make ourselves available at any point in the world on very short notice. VOIP, web conferencing, and satellite technology can find us anywhere on the globe. Cases-in-point are webinars broadcast globally and VOIP, where for nearly free, we can communicate in real-time and webcast our intentions to a global audience. Our world is now connected, more than just a few months ago. System integrators (ie: Accenture, Bearing Point, Cap Gemini, Delliotte, IBM, etc.) are earning billions of dollars connecting various software operating platforms and applications so that business leaders have better visibility into their operations. Moving information more effectively today is the new corporate challenge. Being able to move data and process it - making decisions will be even more important in the years to come. Twenty years ago, moving bits and bites at 300dpi with acoustical couplers was considered average and the high-speed modem was 1200 baud. Today, most firms are abandoning dial-up and one advertiser states that they "don't do jack" meaning the abandonment of the wire and connector. DSL and hi-speed lines continue to move data traffic at astounding speeds (300 baud vs 100M) compared to the movements of yesteryear. Using this capability, firms need to leverage integration of their applications into a collective executive decision support system often referred to as Analytics or Business Intelligence. The challenge is how to connect the numerous niche applications to be able to operate as a unified ERP company-wide decision service and maintenance support process.

The niche decision – was it the right one?

Many large firms have a large number of stand-alone niche service and maintenance applications running. Making the niche decision, selecting best of breed appeared to be the right thing to do at the moment to address a specific service need or service application. Having a human resource (HR/HCM) package, a stand-alone warehouse or inventory system, transportation module or procurement package, all seemed like the right decision at the time. But times have changed. These systems now need to communicate with one another. Inventory needs to communicate with transportation and with procurement. The supply chain needs to be completed by interconnection. The cost burden for this synergy of the multiple disparate niche solutions will be a significant portion of any IT organization's costs. Recent estimates indicate that up to 70% of IT budgets are devoted to maintaining and interconnecting existing applications. So in reality, was the niche decision a good one, hundreds of times over, as the new challenge is how to connect them together? The other alternative may be to look for systems on a common platform or already pre-connected such as from full-suite ERP providers.

Fix it yourself!

Surveys indicate that about 30% of service visits can be avoided by proper care of a skilled or trained operator. Industry is moving toward more highly reliable devices that require less maintenance. When was the last time you changed the spark plugs in your car? With onboard diagnostics becoming more prevalent in products and equipment today, users have the ability to fault locate and repair many of the devices in service. Examples include office copiers or printers that run diagnostics to locate paper jams or failures. We anticipate seeing more CRUs – customer replaceable units, meaning as a part fails or begins to fail, a diagnostic feature will identify the assembly and indicate to the user that the certain part needs replacement. In turn, the product sends a signal to a call center that can automatically run a diagnostic to confirm the error report, and once satisfied that the unit is in degraded mode, then mails a replacement part to the user for replacement. Recent experiments on toner and developer or paper-outages have proven successful with printers. When toner or any consumable begins to run low, even when an oil change is due on your car, a replacement package may arrive at your door one or three days prior to stock outs – a perfect example of lean. The last time I went to Costco and stocked up on toner, I found that by the time I used the last cartridge (as I needed to buy a supply of 50), the toner had solidified or petrified and the cartridge expiration date was 4 years earlier. So the operation here is seamless to the user and perfect from a lean (zero stock) inventory perspective.

Greater emphasis is being placed today on the unit operator to be sensitive to maintenance requirements. On the other hand, management is demanding what seems to be 100% availability. In many cases, operators detect malfunction prior to catastrophic failures, such as motors seizing due to lack of lubricant, of strange noises, vibrations, early alerts or some indicator of possible failure. It is in the best interest of the equipment that the unit be investigated immediately; however logic dictates that if the equipment is engaged in a critical production operation, when taking the unit out of service would result in the loss of perhaps millions of dollars in production volume, then the unit is expected to continue performing despite the possible negative consequences of continued operation (such as in a low oil or overheat condition).

Pay me now or pay me later

One of the best investments that firms can make are the expenditures on periodic service and preventive maintenance repairs on their operating equipment. Mechanical products that involve any type of movement, even fans on electrical equipment, require periodic servicing, cleaning and update to maintain the original integrity and continued reliable performance. When I travel to numerous locations in the world and take taxi cabs to various cities, I often inquire as to number of miles on the vehicle and the frequency of oil and filter changes. One cab in Houston had over half million miles as the driver reported that the oil was changed religiously every 3500 miles. Materials used today in the production of equipment are much more durable then the materials of yesterday. If properly serviced, firms can enjoy many years of productive operation from their assets if they were just properly maintained to the manufacturers specifications. Oil and filter changes along with tire rotations and the periodic 30,000 major services are the best investments car owners can make in retaining the original condition and higher residual value of their vehicles. Being stranded on the highway is never a pleasant experience. Failed fan belts, tires, windshield wiper blades, or hoses are just a few examples of lower cost items that can and should be inspected for wear and needed replacement prior to failure.

Maintenance is a business, not just a service

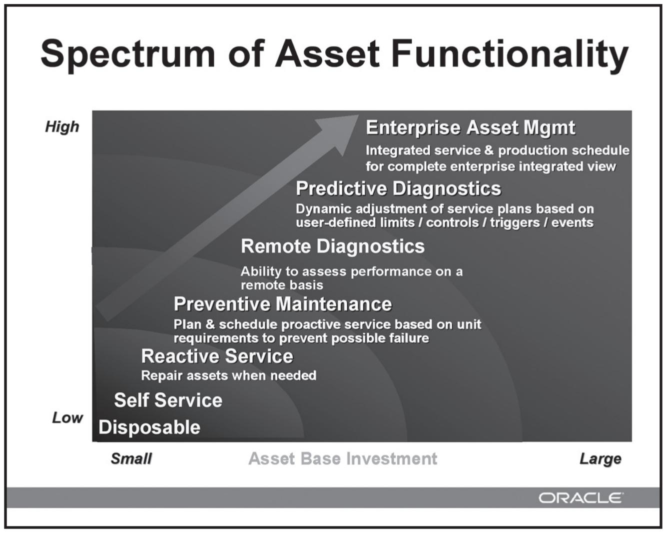
Many think of maintenance as a necessary evil, a cost center, overhead or non-productive. This is far from the truth. Maintenance operations perform a highly valuable service to maintain assets and related production equipment on the condition of its original condition and to provide reliable and economic operation. Maintenance is serious business as it works to comply with safety, health, and quality regulations. Units from fire extinguishers to elevators and escalators need to have documented evidence of inspection and service to perform properly. Picture yourself picking up a fire extinguisher in the time of an emergency to put out an office fire, only to realize the unit is non-operational with an expired tag from 4 years earlier – like my example of the expired printer toner. Fortunately we have inspection laws that require commercial and industrial work environments to be properly protected with the availability of inspected, tested and operating fire extinguishers. The existence of an inspection tag is not the absolute certainty of a functioning device, as certain very low cost providers of fire extinguisher services are known to have delivered and installed non-working units as a scam. Of course firms should be alerted to these scam artists at prices too good to be true because it probably is.

The use of consistent performing service firms is the best assurance for reliable performance. Shaving a few dollars in service procurement by moving to a lower quality lubricating oil or filter is probably not the best avenue for cost reduction. Many firms take this path on a temporary basis that eventually becomes a long-term trend. The performance eventually catches up with the expenditures. Lower quality consumables, from copier toner and developer to lubricating oils and filters for engines to pump seals, although attractive in saving money in the short run, eventually lead to asset replacement in a shorter time period.

Why does this matter?

It matters because critical production may depend on it. From elevators to automatic doors for office entry, to pumps, pipes, tanks and motors in a refinery, proper service and maintenance are crucial ingredients. Having all the information available to make the best possible decision in maintenance planning is important in achieving the proper service and production goals for the operation. It would be unrealistic to attempt to run a major service organization manually, on paper, with numerous clerks, as it was done in the early days of the Industrial Revolution. With the advent of the computer and modern databases, firms now enjoy the luxury of Enterprise Asset Management (EAM) to better control maintenance operations. Advanced programs have been developed to guide firms in optimizing the maintenance approach so that performance can be maintained at a highly reliable state, approaching 6-sigma uptime (99.999+%). Think of the complexity of jet engines mounted on a large airframe that is capable of flite. Jet engine performance at the 99.9% level would yield several crashes per day at failed takeoff – totally unacceptable. As a result, airlines have adopted sophisticated and highly regulated maintenance procedures, coupled with inspections and certifications, to assure proper performance at or above the 6-sigma threshold (3.4 incidents per billion). For this reason, the American airline industry is experiencing one of the best records regarding airline safety and reliability. This safety and reliability model is the envy of industry. If only other operating systems were able to perform at the same level of service, such as our local cable TV provider whose service only seems to fail during playoff games in overtime.

It is significant to note that many firms are satisfied with the way things have been done in the past. Uptake on advanced maintenance has been adopted by those on the cutting edges of competition, innovation and performance in a survival market. Large firms employing thousands in a continuous production model, such as an assembly line, cannot afford to remove assets from service when millions of dollars in production value are at stake. For this reason, firms have adopted the enterprise maintenance model linking together their operating, production and utilities in a fully integrated view for consistent servicing.



Maintenance strategies usually fall into one of several categories depending on both the value and importance of the asset. This diagram depicts the service and maintenance strategy for firms producing products, from razor blades to locomotives. The most inexpensive products are typically never maintained and disposed of after use, called 'throw-aways.' Cell Phones, small TVs and VCRs now fall into this category. Some devices such as copy machines or printers are serviced by their users or operators. More advanced, skilled technicians with the proper parts repair units (eg: washing machines and dryers) typically conduct this service. Moving up the maturity curve, complex or sophisticated devices employing numerous parts and/or of higher value may receive some type of preventive maintenance to achieve proper operation such as the example of regular oil changes for vehicles. With the real-time access of low-cost internet or cell technology, firms can now remotely monitor the performance of their assets to assure proper operations. Unit sensors can transmit temperature or pressure settings along with critical vibration or noise parameters – such as the impending failure of a bearing. Some firms go one step further to even have cameras focused on assets in the event a foreign object such as a tree limb or other foreign or falling object would interfere with operations. Also, low-cost motion detectors alert security in the event a trespasser or animal violated the perimeter zone such as in secure utility or airport operations. Bringing all of this intrusion, operating and malfunction information together into one place becomes the cornerstone for the modern maintenance EAM operations.

Design operations need to develop predictive models for their products. We know when razor blades fail after a few uses and we know when it is time to retire a motor once the seals have failed and replacement parts are no longer available. With assets from pumps to motors, vehicles to airplanes, manufacturers need to make available to users a typical use-model of predictive behaviors. These predictions guide operations through normal or abnormal lifecycles of assets to better predict performance. Returning to the example of the taxi with 500,000 miles, if properly maintained, car engines can have a long life. Several examples of cars going over 1,000,000 miles have been validated. Predictive models help companies plan their future capital and maintenance horizons better. Capital expenditures can be better forecasted while units can operate with improved predictability with the availability of such valuable information.

The highest degree of integration is the Enterprise Asset Management (EAM) state where all of the assets are interrelated and monitored from a single system of maintenance and operations. Using an EAM in conjunction with operating systems for production allows firms to enjoy the great benefits available from reliable production. Examples include transportations firms that need to take assets out of service when on the ground – as it is not possible to remove planes from service in the air, or similarly, locomotives, buses, taxis or monorails during operation.

Single Source of Truth

Having all the information available real-time in one place is utopia. Then, by having this information become 'actionable,' meaning if a parameter should fall out of range (min/max), an alert can trigger immediate investigation and create a service order if needed. Technicians can review the operating condition via remote monitor and compare it with the manufacturer's predictive model. Technicians would know that by operating the asset under the new parameter, such as in elevated temperature, the asset would fall into degraded mode and either shorten the life span or operate uneconomically until the needed repair was made. Operating options would be available instead of just hard-failure. EAM provides the framework for firms to adopt their best practices into operations settings to achieve better performance. However, achieving these goals is easier written than accomplished. To accomplish this end, firms need to adopt IT practices to capture data into a unified database or warehouse for processing with analytics and real-time dashboards for management visibility. Line managers need the drill-down tools to access answers to conditions without leaving their office or the control room. When all this information comes together, assets can work in harmony with each other and maintenance management can move toward the proactive role instead of the traditional role of reactive fire fighting.

Conclusion

To operate in today's competitive world, firms need an integrated EAM system. By working in harmony, maintenance and production assets can yield greater production provided the information is made available to service management. To achieve this end, maintenance management needs to extract the critical asset information to be in a position to detect failures prior to occurrence. Manufacturers need to share with their customers the predictive behaviors of assets so that user firms can be ahead of the failure curve and take needed proactive steps to eliminate unanticipated failures. Computer and communications technologies exist today to help firms achieve this goal; acronyms such as BPEL (Business Process Extension Language) and SOA (Service Oriented Architecture) will become household words in the service and maintenance communities. With prices shrinking for data storage, communications and networks, cost should no longer be a barrier for firms to use available technology to accomplish their desired operating objectives. Tomorrow, with foreign competition growing at expanding rates, it will be the firm that fully leverages its EAM systems in the context of its enterprise information architecture that will achieve competitive advantage.

Managing Business Risk with Facility Reliability Reviews

by Larry Cote, Dofasco Inc.

Abstract

Dofasco understands that reliable equipment is essential to produce quality products on time and at a competitive cost. Therefore, reliable designs and processes are necessary to reduce the risk posed by equipment failures to manufacturing and business goals. More importantly, facility assets and equipment must not fail in such a way that the health and safety of people is affected or the environment is negatively impacted.

Dofasco has developed an approach based on Failure Mode and Effects Analysis (FMEA) to describe failures and assess their impact on short, medium and long-term business goals. Originally developed in 1999 as a way to identify key reliability contributors for capital planning, it is known internally as a Facility Reliability Review. The process uses several key quality and reliability principles and some unique adaptations in a customized FMEA analysis. For example, defining equipment as failed by inadequate design or by poor condition helps to target significant performance shortcomings that have become the way of doing business, but really shouldn't be tolerated.

Introduction

Dofasco is Canada's most successful steel manufacturer, employing over 7,500 people at its main operations in Hamilton, Ontario. In 2002, Dofasco earned consolidated net income of $122.8 million or $1.63 per share, reflecting record steel shipments and excellent operating performance across the organization. The replacement value of the facilities and equipment at that site is approximately $5 billion. For a manufacturing facility of this size and complexity, it is imperative that reliability processes focus on putting systems, practices and methodologies in place to help create delighted customers and improved shareholder value.

In the 1990s, Dofasco experienced a period of contraction, which caused Dofasco to seek new ways to gain and maintain a competitive edge in the changing global steel industry. The result was Dofasco's Solutions in SteelTM strategy: investing more than $2 billion on technology and putting an emphasis on value-added products. Faced with some aging facilities that were supplying competitive markets, decisions had to be made to either make the capital investments necessary to upgrade them or consider getting out of the market for their products and shut down the lines. In one manufacturing business unit this challenge was dealt with in part by conducting a review of equipment related failures of electrical equipment, and summarizing the value of the lost production opportunity for each. The report, entitled "Catastrophic Electrical Equipment Failure Risk Assessment," was submitted in 1998 as part of a justification for significant capital investment. This money was needed to entirely replace the drives and automation equipment for all the processes in the business unit, and the report was considered most useful in gaining approval for the expenditures. That business unit has since become an important and consistent contributor to the Dofasco profit plan.

Similarly, in 1999, another part of the company recognized that process capability needed to be reviewed because of changing customer requirements and issues with equipment obsolescence. This required a more comprehensive review that could easily tie into quality processes within the area, so the original Catastrophic Risk Assessment technique was significantly modified to incorporate many of the standard features of a typical Process or Product-Design Failure Mode and Effects Analysis (FMEA). One of the key quality concepts that drove this change in approach was the usefulness of a Risk Priority Number (RPN) to quantify text-based failure information for filtering and sorting the information. The usefulness of this approach is further endorsed and validated in the literature. [1,2]

Managing Business Risk Over Time

An idea that became the cornerstone of the data collection and analysis process was to continuously review the effect of failures not just in terms of their immediate severity, but also in terms of how they would undermine the ability to meet future expectations. The difference between mid-term manufacturing requirements and the capability of the operating assets is explained as the "Cushion of Capability." It infers that a reasonable cushion, defined as an asset performance standard, must be maintained to allow for normal degradation in performance over time. Figure One illustrates how equipment assets suffer degradation in condition and hence performance over time, and how the level of performance should not be allowed to dip below a pre-defined minimum through a series of repairs or modifications.

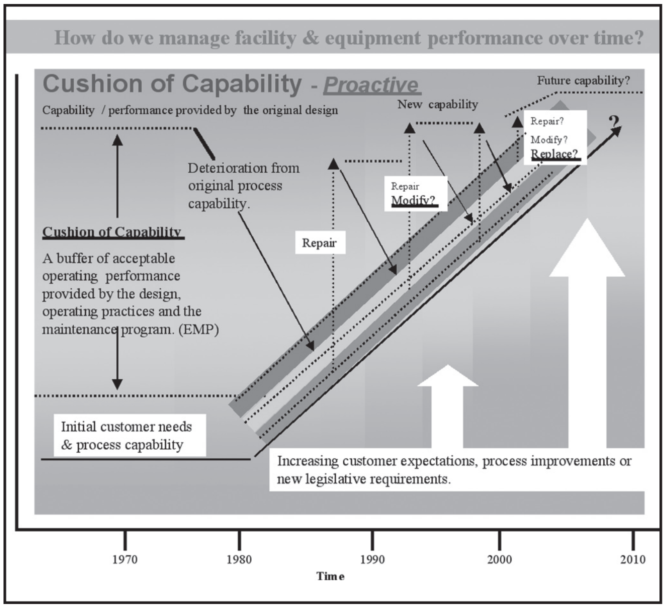


Figure One – The "Cushion of Capability" - Keeping Asset Performance Standards Ahead of Manufacturing Requirements Over Time

An optimum blend of maintenance strategies, consisting of condition-based, time-based, intentional run-to-failure or failure-finding approaches must be brought to bear on the assets whose failures pose significant risk to manufacturing performance. Properly identifying those facilities or equipment assets with inordinate amounts of risk offers up the potential for significant gains by improving process reliability.

Data Collection for the Facility Reliability Review

There are many techniques for understanding and evaluating the reliability of facility assets and equipment, ranging from qualitative to semi-quantitative to highly rigorous quantitative approaches. A key difference in each is the difference in the scope and level of detail that can be examined within a reasonable amount of time while still obtaining useful recommendations for managing reliability as a whole.

In the early stages of development, a decision was made to conduct fairly high level equipment FMEA's at the process level, so that a complete review which takes 2-3 weeks to complete could address 50 – 75 major equipment assemblies for a typical process line. A typical FMEA data collection template was modified to include cues about items of interest specifically relevant to equipment failures and the response to them. [3] It was also adapted to allow the severity of failures to be parsed into specific categories of interest for subsequent grouping, filtering and sorting. The categories, which reflect the basic values of the company that target business goals, are Health & Safety, Energy & Environment, Throughput, Quality, Customer and Cost.

Once again, quality concepts and vocabulary such as reaction and correction plans to deal with failure events were intentionally used to improve the acceptance and understanding in business units with a strong quality and customer focus.

A cross-functional team discusses failures and the information is collected on-line by a facilitator. The team will have representatives from manufacturing, maintenance and technology, and other specialists or service departments are invited to attend as required. The failure information can be described at various levels of major assemblies, sub-assemblies, component level or individual parts, according to the discussion during the data collection and analysis. The scope of the project is well defined to ensure the data collection and analysis does not generalize too much or become bogged

Failure / Loss of Function How does it fail or underperform? How could it fail or underperform?	[illegible]	Reaction / Correction Options How do we restore the function? How do we prevent future loss?	RPN
1-1 "*Failure*" is any of: - broken - limping / slowing the line - damaging the product - hurting someone - environmental damage What is the most common failure of this equipment? What is the worst failure of this equipment?	Safety: Environment: Quality: Throughput: Customer: Cost:	Parts: Knowledge: Restoration: S.O.P's	Frequency x Severity x Detection
[illegible]	PM: How many men, how long, how often?	UN / CO: How many men, how long?	
Modify / Replace: *What must be done to get the performance we need for the next 5 – 10 years?*			
Other capability required: *What other functions / capability is needed or available to get the performance we need for the next*			

Figure Two – Facility Reliability Review data collection template down in too much detail, or explore areas that should be the subject of a separate Facility Reliability Review.

Data Analysis for the Facility Reliability Review

The Risk Priority Numbers assigned to each failure are based on a severity matrix developed by Dofasco. The RPN criteria table, shown in Figure Three, has some key concepts, one of which is establishing the difference between intentional versus unintentional run-to-failure, or identifying equipment components that are failed by virtue of inadequate design or condition. The usefulness of assigning different severity ratings according to a good, consistent RPN criteria is vital to identifying reliability improvement projects. [3] As shown in Figures Four and Five, the individual failures can be sorted by RPN, or failures with high severity can be flagged irrespective of the final overall RPN value, or failure RPNs can be totaled for discrete equipment assemblies. In either case, RPN can be used to identify failure severities that should be addressed by a suitable recommendation.

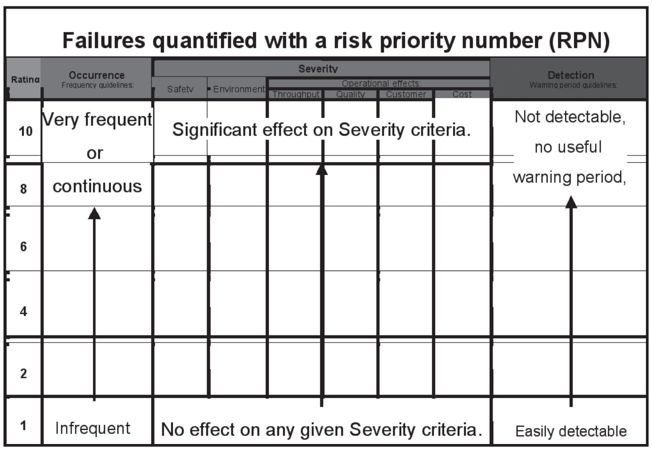


Figure Three – Facility Reliability Review RPN criteria

	No.	Failure / loss of function	Occurrence	Severity	Detection	RPN	Cum Sum	Cum %
1								
2	6	1-6	10	8.3	10	830	830	16.2
3	34	4-11	10	8.3	10	830	1660	32.4
4	41	6-2	10	4.5	10	450	2110	41.2
5	43	7-2	10	3.2	10	320	2430	47.4
6	48	8-3	10	3	10	300	2730	53.3
7	39	5-5	10	2.3	10	230	2960	57.7
8	52	10-1	10	2.2	10	220	3180	62.0
9	25	4-2	10	2	10	200	3380	65.9
10	18	3-1	4	6	8	192	3572	69.7
11	32	4-9	10	1.8	10	180	3752	73.2
12	12	2-4	10	1.2	10	120	3872	75.5
13	8	1-8	10	1	10	100	3972	77.5
14	28	4-5	1	8.7	10	87	4059	79.2
15	45	7-4	1	8.7	10	87	4146	80.9
16	2	1-2	1	8.3	10	83	4229	82.5
17	44	7-3	1	8.3	10	83	4312	84.1
18	17	2-9	1	6.7	10	67	4379	85.4
19	23	3-6	1	6	10	60	4439	86.6
20	51	9-3	2	3.7	8	59	4498	87.8
21	22	3-5	1	5.7	10	57	4555	88.9
22	31	4-8	1	4.8	10	48	4603	89.8
23	19	3-2	1	5.7	8	46	4649	90.7
24	40	6-1	1	4.5	10	45	4694	91.6
25	49	9-1	1	3.7	10	37	4731	92.3
26	47	8-2	1	3.3	10	33	4764	92.9

Figure Four – RPN values for individual Failure Modes

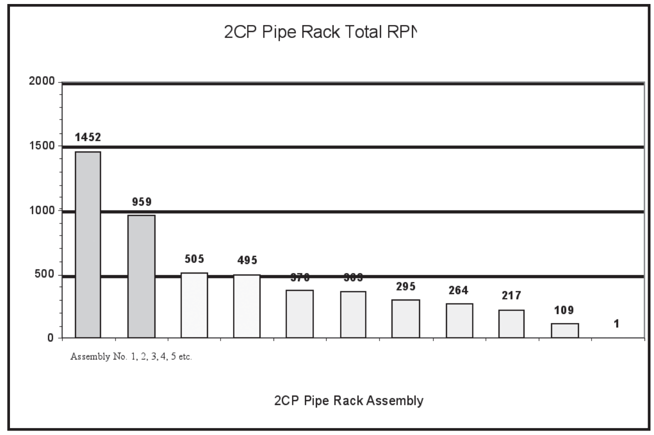


Figure Five – Assembly RPN values

Recommendations are collected at the end of the assembly data sheet during the data collection meetings. Recommendations to address failures that matter are made by answering: "What is needed for this equipment to be able to support the required level of manufacturing performance for the next 5-10 years?" Meaningful recommendations are then described in terms of:

- Opportunities to improve Health & Safety.
- Opportunities to improve Environment / Energy.
- Opportunities to improve critical spares.
- Opportunities to improve knowledge or practices.
- Opportunities to reduce cost.

These can include

- capital projects for new equipment or process improvements
- making repairs or modifications
- conducting design reviews
- making changes to the maintenance program or to operating procedures
- providing training to address specialized knowledge
- improving procurement strategies for critical spares.

The recommendations are not wish lists or solutions in search of a problem; rather they are intended to improve operational reliability, availability and quality. There is no guarantee that any given recommendation will be selected for implementation; they are simply documented for eventual consideration by the leadership group within the area. However, the fact that they are substantiated by a well-documented set of FMEA data that was obtained through a consistent and rigorous process improves the chances of their receiving appropriate consideration and action within a reasonable time frame.

Prioritizing the Facility Reliability Review Data
At this point, it could be thought that all the

information needed to make a good, qualified decision about what to work on is available. During one of the first Facility Reliability Reviews, management asked whether the recommendations for reducing failure severity could be somehow evaluated in terms of the risk they would alleviate. Accordingly, a simple Effort Criteria, shown in Figure Six, was developed by Dofasco to assess the amount of people, time and money that would be required to implement each recommendation.

Estimate the effort needed to address the failures.

Effort Rating	People	Time	Money
10	Many full time people	Months - years	$ Hundreds of thousands
8			
6			
4			
2			
1	A part-time person	Days	$ Hundreds

Figure Six – Effort Rating Criteria

The effort rating for each recommendation is assigned and summed, allowing the recommendations RPN to be plotted in a standard Opportunity Matrix versus the total effort required as shown in Figure Seven.

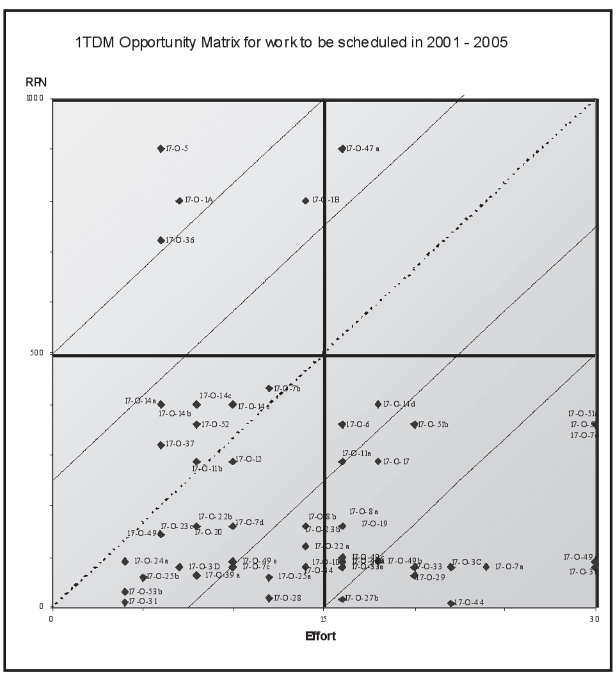


Figure Seven – Recommendation Total RPN versus Total Effort

The Opportunity Matrix helps identify the recommendations that would appear to alleviate the most risk (RPN) from the severity of failures with the least effort, i.e., the least amount of people, time and money. This suggests that those appearing in the upper left-hand quadrant of the matrix should initially be given stronger consideration than those appearing in the lower right-hand quadrant of the matrix. However, this matrix on its own does not provide "the final answer," as the leadership group may have access to other information that can affect the decision-making process.

Data Driven Decision Making

A final management request was to be able to easily view resource assignments for any recommendations selected for projects and to place them on a timeline. Loading the recommendations into a project planning software system easily accommodates this request and allows for dynamic real-time updates and reports to be issued. Although not always taken to this extent for every Facility Reliability Review, it is available and highly encouraged so as to maintain the relevance and usefulness of the information. Figure Eight shows an example of a project plan that could be developed from a Facility Reliability Reviews.

Using the information provided by the reliability review helps the leadership group to better identify what work will be done to improve process reliability and when it will be done. The work is typically managed through a project schedule that tracks activities, costs and resources over a time frame of 1-5 years.

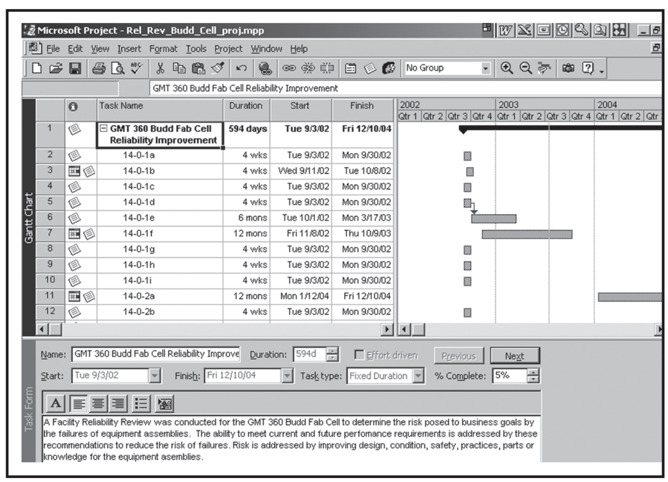


Figure Eight – Project Plan for Reliability Improvement Projects

Summary of the Approach

An FMEA based approach for evaluating the risks posed by failures has been described. The basic steps involved are:

1. A cross-functional team conducts an FMEA of the major equipment assemblies of a process. A key aspect of the data collection phase is documenting the failure information in real time by a facilitator who leads the team through a series of questions to obtain the FMEA information.

2. The failures described in the FMEA are used to create an equipment Risk Priority Number based on their Occurrence, Severity and Detection.

3. Recommendations to address failures that matter are made by answering: "What is needed for this equipment to be able to support the required level of manufacturing performance for the next 5 years?"

When implemented, the recommendations will help improve operational reliability, availability and quality through improvements to process reliability. The risk alleviated by the recommendations is obtained by summing the individual failures addressed by the recommendation. This can be a one-to-one, one-to-many, many-to-one, or many-to-many relationship.

The Results of Conducting Facility Reliability Reviews at Dofasco

The deliverables of the Facility Reliability Review are a failure data set, risk values for each failure, effort estimates for the recommendations to mitigate risk posed by failure, and an opportunity matrix for prioritizing the recommendations. The output of the review is a set of actions needed to ensure process equipment will support current and future business goals in support of customer needs. The actions taken include equipment replacements, redesigns, upgrades or modifications, or improvements to operational and maintenance procedures.

Since being developed in 1999, sixteen (16) Facility Reliability Reviews have been conducted across six (6) production business units at Dofasco. Approximately 3000 failure modes have been catalogued and assessed in terms of their risk to business goals. Significant capital expenditures and other operating improvements have been justified as a result of conducting the Facility Reliability Reviews. Some improvement project are now complete, and can now have their failure information reviewed and updated. This will establish hard data to confirm that Facility Reliability Reviews have reduced the risks posed by failures to a tolerable level, as demonstrated in Figure Nine.

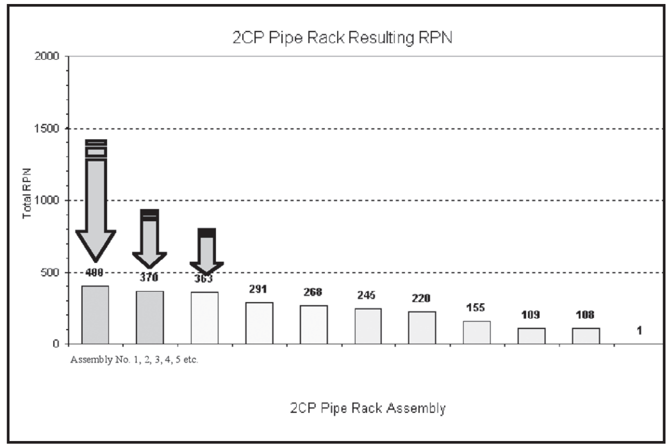


Figure Nine – Reduction of Risks to Business Goals through sustained Gains from Improvement Projects

Taken together, these projects will have resulted in more reliable assets that support improved process reliability and the achievement of current and future business goals toward better shareholder and customer satisfaction.

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