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the magazine for maintenance reliability professionals

RCM vs. FMEA

There Is a Distinct Difference!

What's in Your Plant's

Playbook?

Football and the Game of Plant Performance Improvement

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Elements

Winner of the iPad!

Ken McPheeters, Reliability Engineer, Bunge North America

In the last issue of Uptime, Publisher Terrence O'Hanlon offered a free iPad to the first person to provide the correct sum of all numbers included in that issue's article titles. We received answers ranging from 13 to 224,135. The correct answer was 55,044 . Thank you to everyone who submitted an answer!

Click here to view the chart of the titles with the sum total:
http://uptime4.me/numberschart

Editorial

Get In The Game

IMC-2012! Conference Keynote Speaker

Hear more from Terrence when he concludes IMC-2012 with his keynote presentation Friday Dec. 7th at 1:30pm

In this issue, we invited and challenged "Centered on Excellence" author Darrin Wikoff and global maintenance reliability leadership guru Tim Goshert to write a powerful cover article that would inspire and educate readers on creating sustainable performance results. I think you will agree that they did a masterful job using football (the American kind) as a metaphor for the performance lessons they share.

In most organizations, the only thing that matters is performance. Yes, companies state that people are the biggest asset, but that really translates into people creating performance. People who do not perform are not really assets for companies.

There is nothing wrong with good, old-fashioned capitalism, where the best performers win. They may win on output, they may win on quality, they may win on cost, but high performance organizations always find ways to win.

Why do they win? Many people use the buzzword culture, but I like to call it conversation. I think creating conversations is easier than creating cultures. Most cultures took hundreds of years to establish, yet powerful conversations are created in a millisecond.

If we return to the metaphor that Mr. Wikoff and Mr. Goshert set up so well, let's listen in on the conversations that take place in the stands of a typical football game. "*That *!%$#&* referee blew that call*" or "*coach should have called a pass,*" or even "*great run!*"

These conversations may be interesting as they describe the game, but they have absolutely ZERO effect on the performance of the team or the outcome of the game. You cannot score from the stands; you can only observe.

Contrast those conversations with the ones the players are having on the field. "*I'll score if you give me the ball!*" or "*We are going to win this game.*" These conversations are the game and they determine the outcome. These powerful declarations supercharge performance and create a new future. The players are all willing to be at risk in order to be champions. You experience the game at this level and you earn victory based on the foundation of your commitment.

You never hear committed players complain about conditions on the field. They use the declarative language above that defines the future they see for themselves -- a winning future. Obstacles are simply a condition of the game, not a reason for poor performance. Imagine what you would think if you heard your favorite player being interviewed after losing a game and he described the obstacles as barriers to winning. "We would have won if those guys were not so talented," or "We would have scored if the field was only 80 yards long!"

What types of conversations are you and your team having? Are they like the Monday morning quarterbacks in the stands or at home watching on television? Are they conversations that describe how obstacles define your performance? Are they conversations that judge or complain about others? Are they unsaid things that you hold back?

Or are your conversations more like a player on the field, with something at risk. Do you communicate in a way that creates action and drives performance? Are you willing to make a Declaration of Excellence that will write a new future for you, your family and your organization?

If so, find the people on your team who are willing to have honest conversations and will commit to excellence. Work with this group to make a public **Declaration of Reliability Performance**.

Ask yourself and answer publicly:

What are you committed to?

What do you stand for?

What do you value?

What can you be counted on to provide?

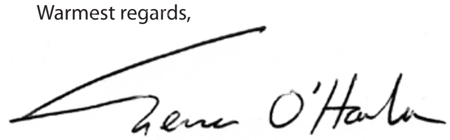
Review this Declaration out loud at every opportunity, but especially at group meetings.

If there is no one on your team that you can make this Declaration to, I humbly offer my services as a committed listener. You can email me your Declaration and I will acknowledge it. If you will be at IMC-2012, please feel free to find me and tell me your Declaration in person. I would be honored to hear it.

With your Declaration, you have left the stands and are now on the field! With your words, you have instantly created a new future. That future will move into the present if you live in commitment, speak with integrity and honor your word. As the new future becomes the present, it will simply look like what's so.

I look forward to hearing your Declaration and to meeting you on the playing field!

Warmest regards,



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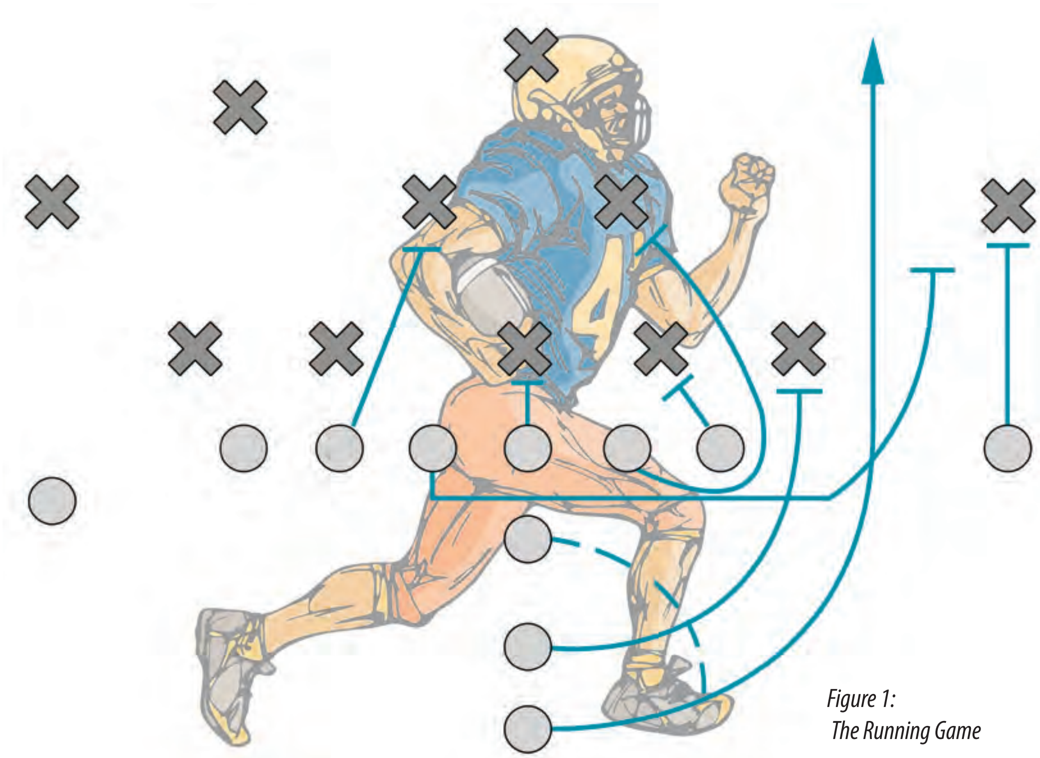


Figure 1: The Running Game

Plant Excellence Playbook

Sustainable Change in Less Than 180 Days

Tim Goshert and Darrin Wikoff

Football and the game of plant performance improvement are similar in many ways. In football, there are four quarters in which the game is played, just like the four fiscal quarters of business. The only score that matters is the one that stands at the last second of the fourth quarter.

In both football and business improvement, a unified team is focused on overcoming losses and making gains towards a predetermined goal. The team, in both arenas, is organized and driven by offensive and defensive game plans aimed at creating a significant competitive advantage. In order to have success on the field, both football and plant performance improvement require discipline, self-sacrifice, dedication, and perseverance.

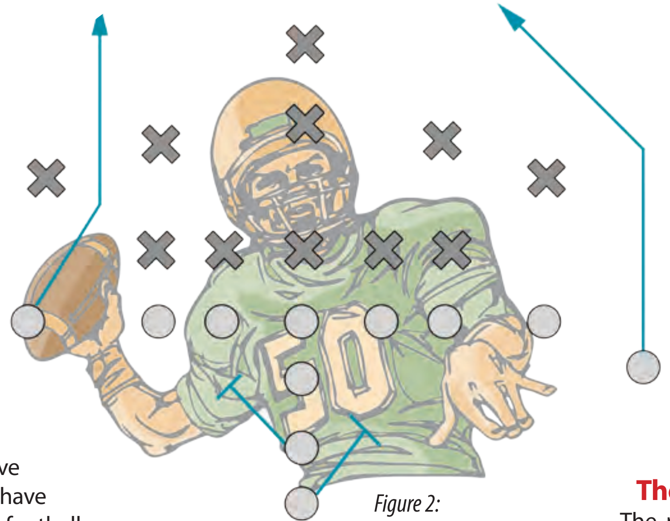


Figure 2: The Passing Game

In this article, Tim Goshert and Darrin Wikoff take us through the fundamentals of both the offensive and defensive game plans necessary for successful overall plant performance improvement.

Offensive Game Plan

Offensive Coach - *Tim Goshert*

The football offensive game plan is designed to score touchdowns against your opponent. This offensive game plan is built to capitalize on your team's strengths that will exploit your opponent's defensive weaknesses. It consists of a mixture of running and passing plays in sequence to move the ball down the field to eventually score a touchdown.

The offensive game plan in plant performance improvement has similar plays. The objective of scoring a touchdown in plant performance is to improve asset reliability, product quality, and customer service as an organization in order to optimize operational and maintenance costs within your organization. Several aspects of an offensive game plan will be outlined further in this article.

The Running Game

The running game in football is best described by former head coach Woody Hayes of the Ohio State University, who preferred an offensive style of play as *"three yards and a cloud of dust."* This area of the game focuses on blocking and overcoming your opponent with pure power and strength. Traditionally, it has been said that the running game is the activity that sets up all further plays in football.

In an operations, reliability, and maintenance improvement process, the running game equates to completing the required foundational work processes needed to support future reliability and maintenance processes. Some examples of these critical foundational areas are asset identification, criticality assessment, equipment failure mode analysis, and Equipment Maintenance Plans (EMP) based on failure mode analysis work.

These four fundamental areas are critical for supporting much of the future work processes. Asset identification processes ensure that current assets in the facility match the operational database's (enterprise asset management system) organizational hierarchy. Equipment criticality assessment processes provide an organization with a view and framework for knowing how critical a certain piece of equipment is to business performance. Failure mode analysis dissects possible failure modes of this equipment and outlines consequences to the business. All of the above processes are used by the organization to develop an EMP, which fully describes the proper maintenance strategy or plan to maintain the equipment in a manner that meets business requirements.

The Passing Game

The passing game in football is designed to gain significant yardage on each play. Short screen passes, post pattern passes, and over the middle passes all try to gain five plus yards per play. These are quick small activities to give the team a lot of yardage and leverage.

In plant performance improvement, several activities provide significant long-term gain, such as Reliability Centered Maintenance (RCM) analysis, Root Cause Analysis (RCA) and Condition Based Monitoring (CBM) tools. RCM analysis processes focus on understanding critical equipment failure modes and their consequences and mitigating actions to prevent failure. RCA focuses on past failures that have occurred and analyzes these events so the organization can understand and implement solutions to prevent reoccurrence. CBM processes provide surveillance activities for understanding the asset's current health and recommend actions to maintain and improve asset health. These processes focus on proactive activities that identify and provide solutions to short-term and long-term problems that inhibit production, quality, safety, environmental, and cost performance. These activities all provide the organization with solutions that eliminate process and equipment failures in the future. The focus is on elimination of defects and areas of waste.

Third-Down Conversions

In football, the offense's third down conversion requires a team to execute under pressure in a precise manner. This play is a critical point in which the offensive must gain the needed yardage to "move the chains" and get the opportunity for four more offensive plays.

In plant performance improvement, precision execution is also required. Two of the most important areas are in lubrication and work execution by the craftspeople. Lubrication requires that the five Rs are executed. They are the right lubricant in the right amount at the right lubrication point at the right time using the right procedures. Attention to detail is important in application and contamination control. Work execution procedures by craftspeople require precision balance, precision alignment, and precision tolerance procedures in all applications. These procedures enhance and help ensure equipment reliability and performance.

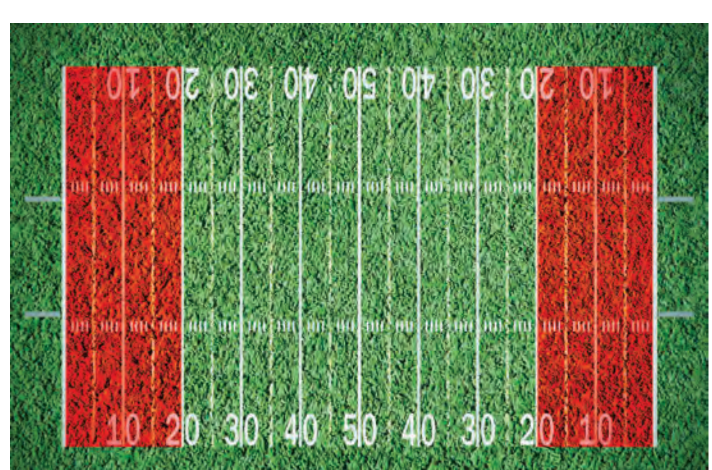


Figure 3: The Red Zone

Red Zone Offensive

The objective to any red zone offensive is to score a touchdown. We want to score seven points in every opportunity in the red zone. Football games are won and lost in the difference between scoring red zone touchdowns and settling for red zone field goals. The winners score touchdowns.

As in football, the wins or losses of your plant performance improvement process is based on how well you execute the right work. Work management processes need to be designed, agreed upon, and followed by the organization to enable work to be performed effectively and efficiently. All of the proactive efforts (EMP development, RCM, RCA, CBM, and Preventive Maintenance (PM) job plans development) that the organization completes in preparation for work execution allow the right work to be completed. Work planning, work scheduling, and work coordination activities prepare for the work to be done in an efficient manner. Fully trained craftspeople in precision techniques allow the work to be completed in a quality manner. Work execution is where the organization reaps the benefits of improved operational performance, increased equipment uptime, better quality products, and an optimized operational cost.

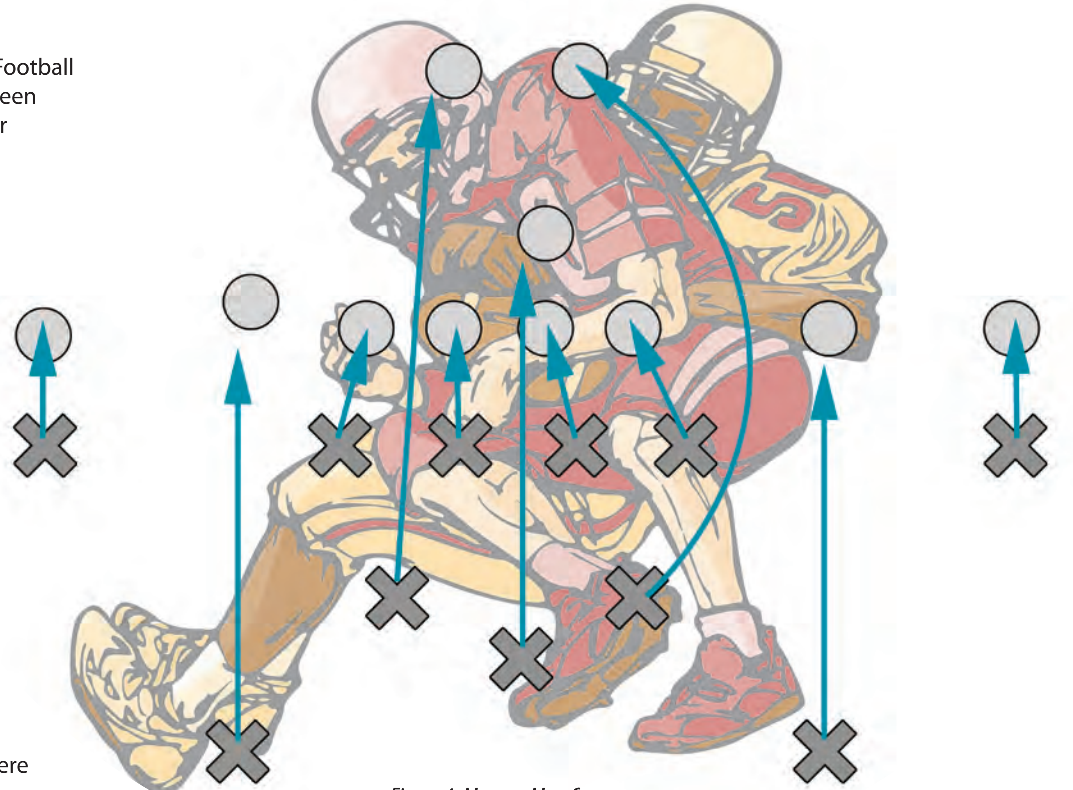


Figure 4: Man-to-Man Coverage
"Get the winners in the game." --Bear Bryant

The offensive game plan described can allow your organization to succeed and win in improving plant operational performance. However, as in football, an offensive team requires a defensive team to have a winning game plan. Next is a description of a winning defensive game plan for your organization.

"Set goals - high goals for you and your organization. When your organization has a goal to shoot for, you create teamwork, people working for a common good." — Bear Bryant

Defensive Game Plan

Defensive Coach - *Darrin Wikoff*

In the context of overall plant performance improvement, the defensive game plan is one of risk management. Vince Lombardi, the legendary coach of the Green Bay Packers, once said, *"If it doesn't matter who wins or loses, then why do they keep score?"* I take this to mean that if we're not focused on achieving a better, more competitive outcome, then why play the improvement game at all? Of course it's about winning! The reason your company has decided to embark on a maintenance, reliability, or operations improvement journey is because they want to beat the competition and win the game of who can get the most customers. This requires a focus on defending against the opposition, and specifically, their impact on your team's ability to win.

There are many risks on the performance improvement field of play, too many for players to see during the game. Therefore, leadership, like coaches on the sidelines, must anticipate the opposition's every move and deploy a game plan that fills the gaps, crashes the corners, and effectively covers players downfield who have the ability to undo the gains made by the offensive game plan.

There are a number of defensive formations used in football. As the opposition's game plan is revealed, defensive coordinators must deploy a package that stops the opposition from improving their position. The same is true in the performance improvement arena. As change risks become evident, coaches and project coordinators must be able to reach into the defensive playbook and call the right countermeasure. There's no time to waste, only seconds on the clock, and if the defense isn't ready, the opposition will score and make it harder for your team to win the game.

Man-to-Man Coverage

The first defensive formation that must be in every playbook is man-to-man coverage. This formation is the most aggressive because it requires a member of the improvement team to guard or defend against a key, influential player on the opposition. Defensive coordinators should deploy man-to-man coverage in the early stages of the game to build awareness of why the improvements being made by the offense are necessary and how they will impact employees. This formation proactively prevents resistance in the trenches.

Resistance, although a risk to the offense's success, is a very natural part of the individual change process. In this context, resistance refers to individuals who are actively heading in a direction that could negatively impact the result the offensive team is trying to achieve. Opposing, resistant formations would include people working outside established standards, people talking openly and negatively about the necessity of the change, or people simply refusing, passively, to execute new practices. Peter Senge, Senior Lecturer in Leadership and Sustainability at the MIT Sloan School of Management and author of the book, *The Fifth Discipline: The Art & Practice of the Learning Organization,* says that "people don't resist change, they resist being [forced to] change." For most people, resistance stems from a feeling that change is being forced upon them without considering their input, experience, or abilities to execute the change. As a result, your defensive playbook must find a way to engage them and capture their concerns, fears, and ideas.

The defense's objective in man-to-man coverage is to create a desire to accept and embrace the change. This is accomplished when those actively involved in the change seek out one or two people from within their natural circle of influence to communicate why the change is happening and how it will benefit them in their role or personal life. In this formation, each member of the improvement team assumes an advocate position. The position requires team members to keep an eye on their opposing counterpart and read the signs that indicate the individual has not yet accepted the change. Once the potential for resistance has been identified, the player must close the gap or intercept the route and reinforce the change through their relationship with the individual.

Zone Coverage

Zone coverage is a less aggressive, but very effective and necessary defensive formation. Zone coverage allows the defense to monitor several areas of the field while the players in the trenches are aggressively attacking the gaps. Typically, the zones needing to be covered on your "field of play" relate to the areas or functional departments impacted by the performance improvements deployed.

The objective of this formation is to oversee specific areas of the field and remove threats in each zone. Unlike man-to-man coverage that focuses on personal communication and relationships, zone coverage is more of a governance formation. Playmakers in this defensive formation are the area managers. These positions must have the ability to see what's going on in the trenches and make a positive play on the ball when these efforts come into their zone. Playmakers must be actively engaged in the play as it unfolds, carefully watching for a change in the expected outcome so they can adjust their coverage as necessary to prevent the opposition from gaining momentum.

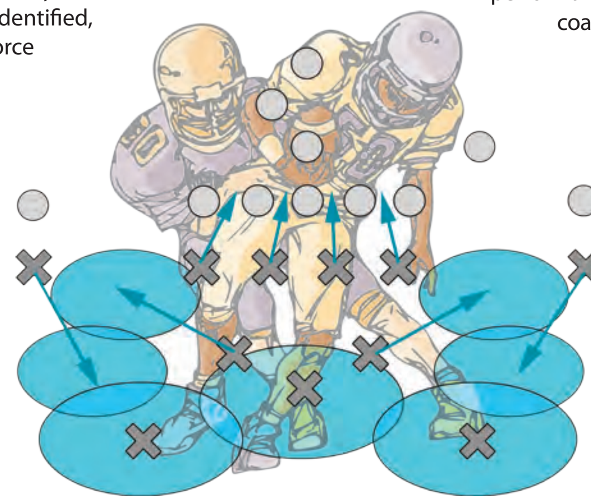


Figure 5: Zone Coverage

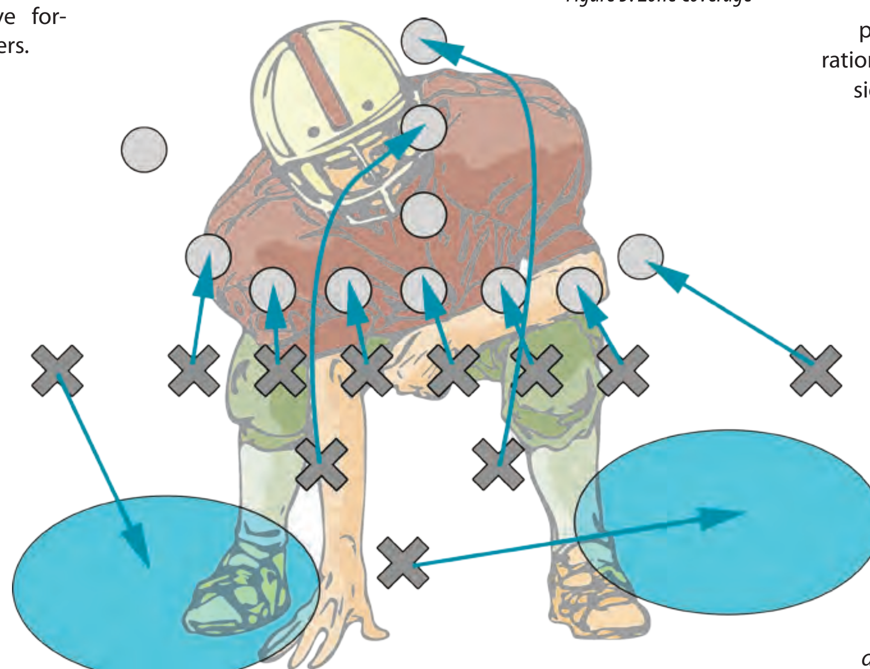


Figure 6: Goal Line Defense Formation

Goal Line Defense

The third and final formation that must be in place to ensure a short turnaround on your improvement investment is the goal line defense. The goal line defense formation is most commonly used in football to prevent the opposition from gaining small yardage, like in a third and short or goal line situation. In the performance improvement field of play, a goal line formation can help anchor the changes made by the improvement effort and prevent inefficiencies from impacting results short term. Near the end of the game, improvements have been executed, but employees are still perfecting their skills associated with the new practices. In short, mistakes are innocently made that may affect the overall outcome of your initiative. The goal line defense is there to prevent mistakes or ensure that these errors don't have an impact on the final score.

The playmakers in the goal line formation are a combination of on-field coaches and daily management systems. The objective of the field coaches is to identify when a new practice is not yielding the right result and quickly diagnose if the problem is systemic or attributed to a training deficiency. The field coaches use indicators, similar to a defensive back watching how the opposing backs line up, to make adjustments to prevent a less than desirable result. Daily management systems, like visual controls and process performance indicators, help the field coaches read the play.

Conclusion

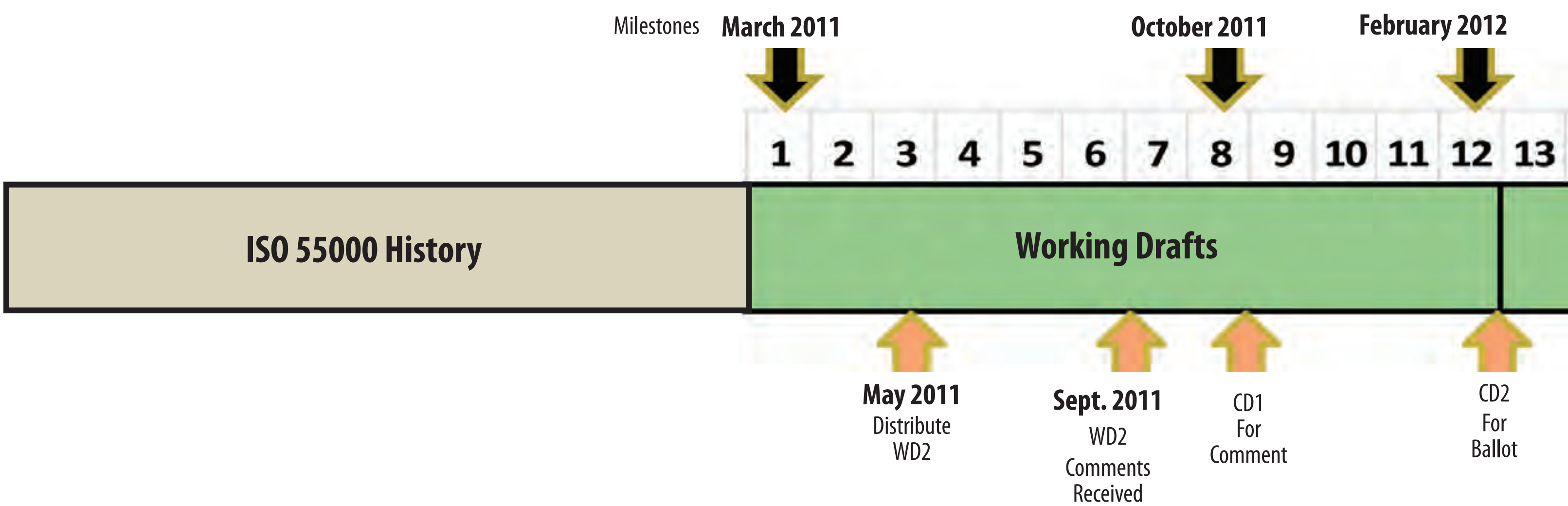
Unlike football, in the arena of performance improvement, you only get one chance at winning. Too many mistakes or missed opportunities and the season is over. Sustainable change is the result of both the offensive and defensive game plans being executed in collaboration. Focusing narrowly on any one side of the ball will only delay your return on investment and may even cost you the game. Teamwork is needed to achieve success. Business leaders, like coaches on the field of play, must ensure that the entire team understands the game plan and their specific role on the field and executes according to plan. Before you head onto the field, make time to walk through the game plan and prepare your team. Never forget: *"How you respond to the challenge… will determine what you become after the game, whether you are a winner or a loser."* - Lou Holtz

Timothy Goshert, CMRP, has 33 years of experience working in the food processing industry. He has extensive experience in plant operations management, project engineering, construction management, and maintenance & reliability management. In 2012, Tim retired from Cargill, Inc. and joined Allied Reliability Group as Principal. He is responsible for strategic customer account satisfaction and business development. www.gpallied.com

Darrin Wikoff, CMRP, is a Senior Instructor/Change Managment Professional with Allied Reliability Group. For the past 10 years, he has continued to coach and mentor many of the world's industrial leaders through the rigorous process of implementing and managing reliability improvement initiatives in support of Operational Excellence. www.gpallied.com Darrin is the author of the book, Centered on Excellence, available at www.mro-zone.com

ISO 55000 Asset Management Standards: Timeline

There is a 28-country effort being coordinated by the International Standards Organization (www.iso.org) to create a new standard for an Asset Management "managing" System. It will be titled ISO 55000 and if your company is already using ISO 9001 and/or ISO 14001, we suggest that ISO 55000 should be on your near term radar. Uptime Magazine is a voting member of the U.S. Technical Advisory Group and you can count on us for future guidance. ~ *Terrence O'Hanlon, Publisher*



2000: NPMA and ASTM International establish ASTM Committee E53 Asset/Property Management Systems Standards
https://www.npma.org/Pages/ASTM.htm
http://www.astm.org/COMMITTEE/E53.htm

2004: IAM developed PAS 55 published by BSI http://theiam.org/

2008: PAS 55 v2 published by BSI
http://shop.bsigroup.com/en/ProductDetail/?pid=000000000030171836

Winter 2009: BSI proposes PAS 55 as the basis for an ISO Management Systems Standard for Asset Management • http://theiam.org/products-and-services

Spring 2009: ASTM E53 decides to engage in the ISO Asset Management standards development process

November 2009: ASTM E53 approved as official U.S. Technical Advisory Group (US TAG) by ANSI • www.uspc251tag.org/

June 2010: Preliminary Meeting of ISO Asset Management Committee in London, England

September 2010: ISO approval of PC 251, Asset Management Systems

January 2011: First Working Draft (WD1) released

February 2011: U.S. comments on WD1 submitted by US TAG

March 2011: First Official Meeting of PC 251 in Melbourne, Australia

April 2011: Working Draft 2 (WD2) released for comments

June 2011: US TAG Face-to-Face Meeting at ASTM HQ in Philadelphia, PA

August 2011: U.S. comments on WD2 submitted by US TAG

October 2011: Second Official Meeting of ISO PC 251 in Arlington, VA (hosted by US TAG)

November 2011: First Committee Draft (CD1) for comments released

Legend

- History
- Milestones
- Drafts/Comments/Meetings
- Editorial Review and Translation
- ISO processing/preparation time

Terminology

ANSI – American National Standards Institute

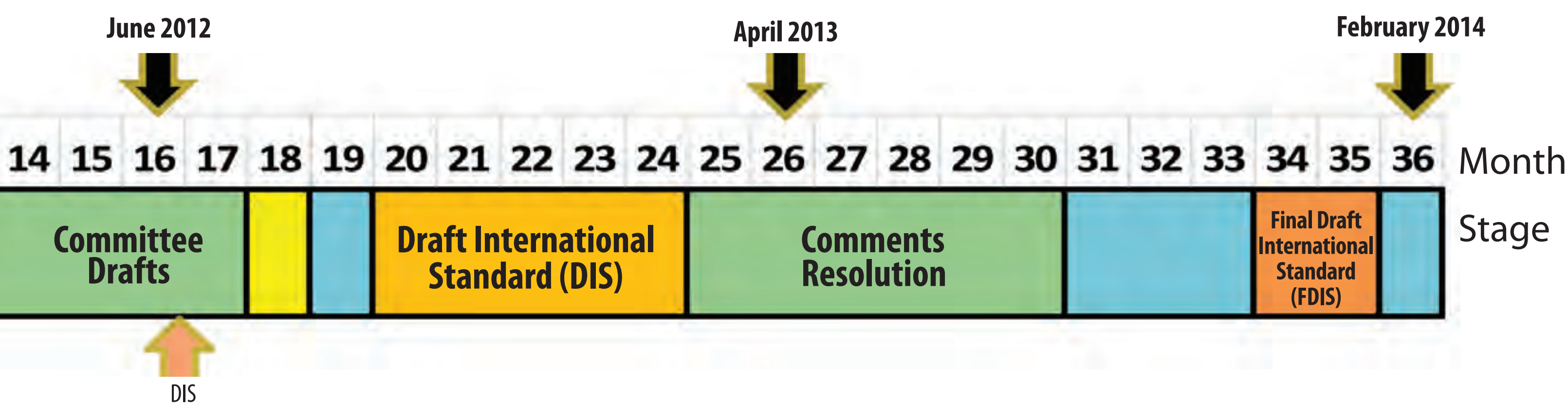
ISO – International Organization for Standardization, European based developer of international standards

ASTM – ASTM International is a U.S.-based developer of international standards

PC 251 – ISO Project Committee tasked with developing a management system standard for Asset Management

U.S. Technical Advisory Group (US TAG) - ANSI sanctioned U.S. group participating in PC 251

ASTM E53 – ASTM standards committee for asset management standards and the ANSI sanctioned host of the US TAG to PC 251



December 2011: US TAG Face-to-Face meeting to craft U.S. comments at AMP Conference in Bonita Springs, FL

January 2012: U.S. comments on CD1 submitted by US TAG

February 2012: Third Official Meeting of ISO PC 251 in Pretoria, South Africa

March 2012: Second Committee Draft (CD2) for comments released

April 2012: US TAG Face-to-Face meeting to craft U.S. comments at Meridium Conference in Jacksonville, FL

May 2012: U.S. comments on CD2 submitted by US TAG

June 2012: Fourth Official Meeting of ISO PC 251 in Prague, Czech Republic

September 2012: Draft International Standard (DIS) released for ballot and comment

January 2013: US TAG Face-to-Face Meeting to discuss, comment and vote on the DIS for Ballot

February 2013: US Vote and Comments on DIS to be submitted by US/TAG

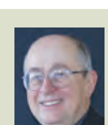
April 2013: Fifth Official Meeting of ISO PC 251 in Calgary, Canada

October/November 2013: Possible early release of ISO 55000

November/December 2013: FDIS ballot (if necessary)

February 2014: Target date for the release of ISO 55000

Publisher's note:
What do you think ISO-55000 Asset Management Standards mean for maintenance reliability professionals? Email Uptime Magazine Publisher Terrence O'Hanlon: tohanlon@reliabilityweb.com.



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Work Execution Management

cMms computerized maintenance management system

You Deserve Your 3 "RIGHTS"

Deploying Your CMMS for Effective Inventory Management Towards Maintenance Excellence

Tarek Atout

All manufacturing organizations own a warehouse for MRO spares and most of these organizations use a computerized maintenance management system (CMMS) as a tool to support the maintenance function. This article will focus on the integration between CMMS modules that serve maintenance, mainly work order, inventory and purchasing.

But first off, let's emphasize some important facts:

- MRO spares exist to support maintenance functions. If equipment to be maintained is not there, then spares and all MRO spares organizations are not required. No need to keep a spare tire if you don't have a car.
- CMMS by name is a maintenance management system and accordingly, all modules in the system must be deployed to serve and support the maintenance process. The inventory/purchasing module is critical in this regard.
- In maintenance organizations, deep focus must be on materials management rather than inventory control and warehouse management, the difference should be clear.

Maintenance excellence

Maintenance excellence can be defined as achieving at a performance level demonstrated as "best in class" by the leading organization in a given industry. In other words, "perform effective and efficient maintenance without waste" or simply "waste elimination from the maintenance process." The benefits of eliminating waste are effective functions and high key performance indicators that match the output of leading companies.

What waste to eliminate?

Material-related losses that impact maintenance performance can be translated to time and then to cost. The main bad factor that will cause disturbance to all maintenance activities is being out-of-stock of a critical item. Stock outs will add:

- Increased equipment down time;
- Production interruption costs;
- Unutilized manpower costs;
- Extra costs for expediting emergency orders to overcome stock outs;
- Probable cost of overpricing of the required spares;
- Costs of interruption to maintenance schedule;
- Safety considerations for some equipment.

Other spares-related losses that influence maintenance effectiveness are:

- Incorrect items identification, procurement, or planning;
- Wrong parts kitting by stores staff;
- Time spent to find alternative part;
- Time spent locating parts in the store;
- Additional carrying cost for excess inventory.

The above are obstacles against a smooth maintenance planning and scheduling strategy that lead to lower craft utilization and reduced wrench time. Low productivity and high cost are two threatening enemies to maintenance excellence.

Balance of different perspectives

There are two different perspectives when each partner looks at MRO spares. The maintenance team views spares as enablers to execute their jobs on time and meet the schedule. They need the right part now or when the job is due. The inventory team is concerned about usage, stock quantities, calculation and ordering. These two views are not contradicting, but integrated together with the ultimate objective of creating a balance between the inventory value and the customer service level without any adverse effect on asset reliability.

CMMS and your 3 "RIGHTS"

Can CMMS be used to eliminate, or at least reduce the above waste and create the required balance? The answer is absolutely "YES," if we refer to the traditional definition of the MRO spares function: "Provide support to maintenance to have the RIGHT PART in the RIGHT QUANTITY at the RIGHT TIME."

Using a mathematical expression, the RIGHT PART is a function of accurate equipment bill of materials, equipment usage history and failure history. The RIGHT QUANTITY is a function of equipment and part criticality, historical usage quantities, consumption rate and lead time. The RIGHT TIME is a function of a proactive maintenance environment with a well designed and implemented planning and scheduling process, with vendor lead time also a factor.

All these factors that impact the above 3 "RIGHTS" can be easily extracted from a successfully implemented CMMS.

CMMS lifecycle

The lifecycle of the CMMS consists of five major stages: selection, implementation, training, usage and continuous improvement that ensure the system will always give the expected results along the whole usage life.

The lifecycle of any CMMS starts from the selection process, although many people like to start it from the implementation phase. However, selection is the better starting point because it has a significant impact on the other lifecycle phases.

CMMS for effective MRO spares management with maintenance in sight

Selection: There are many factors that govern the selection of a CMMS in relationship to your needs with other system functions' specifications. It is imperative that the selection committee consists of representatives from all departments that will use the system. Although maintenance teams are leading the process since maintenance is the driver for other functions, all other departments must be there. Members from stores, purchasing, IT, finance and maintenance should constitute the committee.

Materials-related specifications and the capability of the CMMS can be classified into two categories according to the perspective of the user function:

Inventory/Purchasing team perspective

- System will notify user when a quantity on hand drops to the reorder level.
- Maintains storage locations and stock storage levels information (on hand, reserved, on-order, max-min, etc.).
- User-defined method for tracking items' prices according to company accounting system.
- Supports multiple warehouse system.
- Purchase requisition is triggered when items reach their reorder points.
- Vendor management considerations:
  - Capability to integrate with vendor's own purchasing system;
  - Link between vendor and parts (vendor parts and part vendors);
  - Criteria for vendor evaluation (volume purchased, lead time, delays, shipment accuracy, damaged goods, invoice accuracy, etc.).
- Has the ability to make different types of materials analysis (ABC, XYZ, etc.).
- Supports the physical inventory count process.

- Definitions for spares storage conditions.
- Tracks items' lifecycle history from creation to disposal.
- Advanced search and sorting capabilities.

Maintenance team perspective

- Provides a bill of materials for each equipment asset and its reverse (where-used).
- Able to cross-reference any spare to substitute spares that are also in stock.
- Criticality assignment for each part.
- Able to forecast materials requirements for preventive maintenance due for any specified period.
- Able to track the planned and actual materials costs for each work order.
- Able to track materials consumption history and costs for all equipment.
- Able to notify user when consumption rate of a specific item highly exceeds the rate of previous periods.
- Able to reserve the planned materials of the approved work orders.
- Able to notify the planner when a planned part is received.
- Able to track requisitions, purchase orders and receipts of all items.
- Ability to order non-stock items.
- Able to flag and report all awaiting materials work orders.
- Links equipment failure modes with used parts.
- Provides stock storage levels with complete technical data.
- Able to produce different key performance indicators reports for all functions.

The ultimate selection criterion is to have a fully integrated inventory and purchasing system function with maintenance function.

Implementation: One of the most important links between the maintenance order and the inventory module is the bill of materials (BOM) definition. BOM is the list of parts and components that makes up a specific asset. It must be accurately defined for all assets; critical assets must be completely linked with its BOM. All critical items must appear in assets BOM. The BOM definition for any asset is linked with asset commissioning in finish-to-finish relationship, with no justification for delaying that job after the asset is online. When building bills of materials, keep in mind that they are the main source for materials requirements for maintenance work order planning. The planner will refer to these lists to properly plan the work and identify spares needs. BOM and its reverse (where-used) are in strong relation with the equipment and will be very useful for any design changes, decommissioning, or related reliability studies.

Training: As a key phase of the CMMS lifecycle, it is recommended to conduct training sessions with a mixed staff of maintenance, stores and purchasing for specific topics. A separate training session for each department only promotes an isolated work environment. Maintenance and stores teams must have the same understanding, view and interpretation for the common topics so after the training they will go together in the same right direction, no intersections. Training must not focus solely on how the system functions, but also why. Sessions must be educational and facilitate brainstorming on the philosophy of the integrated modules. As shown in the lifecycle graph in Figure 1, training is the link between implementation and usage. Failure to do constructive training will badly affect the usage quality and consequently lead to end of life very soon.

Usage: The above three stages of the CMMS lifecycle can be considered investments while "usage" is the return on investment (ROI). The large sum invested in the CMMS will only provide a return with professional usage. Management and users must focus on the quality and integrity of data. Data quality is concerned about completeness and accuracy while integrity is concerned about the effect of bad data in a specific module or transaction to other integrated ones.

The objective is to improve the value of the data provided to management for analysis and decision making. The first action is to assure that NO maintenance, procurement, or inventory transactions are executed outside CMMS.

The way to bad data quality (usage stage)

The following actions will restrict the value obtained from your data and your 3 "RIGHTS" will become too far gone to catch:

- Work requests are not raised promptly.
- Work orders are not closed promptly.
- Unused materials are not returned to stores.
- Hidden stock with technicians.
- Spares are issued for blanket work orders.
- Unclear materials loan policy.
- Materials reserved only for "in case of."
- Inaccurate dates of transactions.
- No on line process for stock levels adjustments.

Continuous Improvements: This covers the future care of the system and the nonstop fine tuning throughout the CMMS life. The more care, the longer the reliable life. The following actions are regularly required to assure continuous improvements:

- Maintain data quality/integrity.
- Conduct user refresher training.
- Install vendor version updates.
- Make system configuration enhancements.
- Conduct customer satisfaction surveys (end users).
- Perform regular data audits.
- Any changes in the CMMS assets/spares data must be authorized through a defined management of change process.
- Establish a steering (follow-up) committee to advise on system utilization.
- Implement incentives and/or enforcements for CMMS best practices users.

Conclusion

For materials modules in the CMMS to effectively serve maintenance functions, they must be totally integrated with the work order system. A proactive maintenance environment is a key success factor for integrating these two functions. Materials management will not be effective if "firefighting maintenance" is in place.

Great statistics on the subject can be found in the Reliabilityweb.com 2011 CMMS Best Practices study by Steve Thomas and Terrence O'Hanlon. Refer to this study for practical numbers on how users respond to different queries in the CMMS lifecycle.

Tarek Atout, CMRP, is currently a maintenance planning engineer in Qatar Gas in their new expansion project. He has 20 years of experience in maintenance planning and scheduling in oil and gas industries. He has worked in many countries in the Middle East, e.g., Egypt, Syria, Abu Dhabi and Qatar.

Cause vs. Contributing Factor

An Important Aspect in Root Cause Analysis

David Gluzman

The root cause analysis (RCA) method utilizes cause and effect linear and branching approaches by asking multiple "why" questions as an effective way to identify one or more low level conditions leading to a failure. This allows development of a set of corrective actions that will prevent failure in the future. The cause(s) at the lowest level is frequently termed the root cause(s). The purpose of this article is not to present a course on the well-known method, but rather to offer a view on certain details and suggest modifications that are crucial for clarification of the method.

Cause and effect mapping employs cause/effect block chains and formal logic operators between the blocks, thus allowing branching for easy visualization of the analysis process discussed in detail in the narrative. Most proponents of the method do not recommend differentiating the causes by using terms like "major cause," "minor cause," "immediate cause," "intermediate cause," etc. Instead of differentiating causes by importance or order, they suggest differentiating corrective actions on the basis of feasibility, effectiveness, etc. With this approach, after the analysis is complete and the cause and effect map is built, it is up to the stakeholders to decide which of the root causes deserve more attention. While this approach makes a lot of sense, some proponents also do not recommend using the term "*contributing factor*" as a type, which is the reason it is being addressed here.

Terms and definitions are frequently being used rather loosely and, being borrowed from day-to-day interpretation, ultimately lead to fuzzy discussions. To avoid confusion in the RCA process, the definitions used in the narrative and cause mapping will be introduced here first. I suggest using two terms: *cause* and *contributing factor*. The reason for using two terms rather than one will become clearer later in this article.

The dictionary defines the term "cause" as a producer of an effect. It means if there is an effect, there must be a cause(s) producing it. Therefore, for the purpose of RCA, the term will be defined here as:

CAUSE is a condition that produces an effect; eliminating a cause(s) will eliminate the effect.

The dictionary defines the term "contribute" as giving with others for a common purpose; helping to bring about a result; exacerbating something; acting as a factor. For instance, when people give to a heart disease research fund, it is said they contribute to this fund or purpose. However, if someone refuses to give, the fund's assets may be smaller, but it will still exist. Therefore, for the purpose of RCA, the term is defined here as:

CONTRIBUTING FACTOR is a condition that influences the effect by increasing its likelihood, accelerating the effect in time, affecting severity of the consequences, etc.; eliminating a contributing factor(s) won't eliminate the effect.

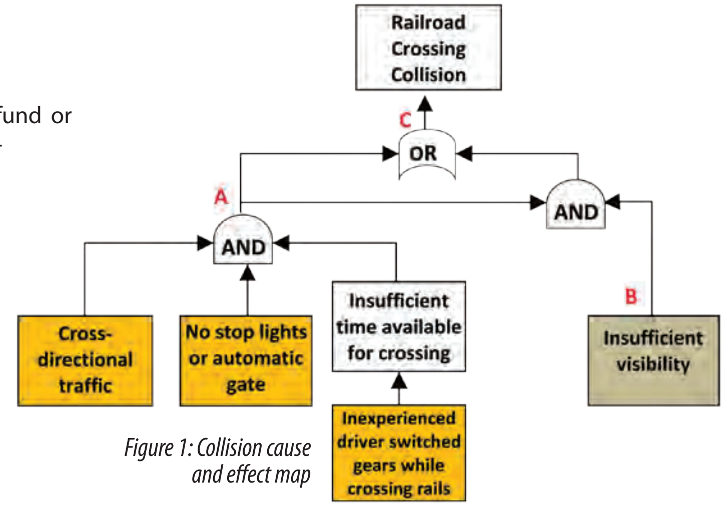

Figure 1: Collision cause and effect map

This concept will be demonstrated by analyzing a hypothetical traffic accident. Picture a failure event - a collision between a train and a car at a railroad intersection. The investigation revealed that the rail crossing had no signal lights/automatic gates; the car was equipped with a manual shift gear; the driver was switching gears while crossing the rails, thus wasting valuable time; and since the collision occurred during the twilight hours, visibility was not perfect. It is clear that the following conditions definitely affected this failure:

- intersecting traffic,
- no signal lights/automatic gates,
- inexperienced driver.

As a general comment it is worthwhile to mention that during any investigation, the participants frequently name conditions that have had influence on the failure event as *contributors*. It likely happens because people are invoking casual day-to-day terminology instead of applying terminology established for the method. This action may cause confusion because in light of the *cause* and *contributing factor* definitions given previously, it may not be accurate. It will be shown below that the aforementioned conditions are, in fact, the *causes*.

Note that all three conditions have to be true in order to produce a collision effect. On the other hand, if, for instance, the signal lights/automatic gates were present, the car wouldn't be able to cross the rails and no collision would have occurred. The same is true for the two other conditions. Therefore, on the cause and effect map, these conditions have to be connected with a logical gate "AND." As far as corrective actions are concerned, by correcting one, two, or all three conditions, collisions will be prevented from future occurrence. For instance, by building an overpass, no intersecting traffic at the same elevation level is possible. Therefore, any of these conditions meet the definition of a *cause* (yellow shaded blocks in Figure 1). Obviously, to get to the fundamental level (root) cause, one can dig deeper, but this is not the point of the discussion.

On the other hand, the insufficient visibility condition is of a different nature. If true, it physically affects collision by increasing its likelihood. Improved visibility alone may only increase the likelihood of detecting the train earlier, however, it can't reliably eliminate the collision. Note that the formal logic in the map properly represents this situation.

The "OR" gate output (failure event, Point C) replicates the status of the causes output (Point A) and disregards the insufficient visibility status (Point B). When at least one cause is corrected, the collision is also corrected. The opposite is also true. Correcting the insufficient visibility condition (which makes Point B false) will have a correction effect on the failure event (Point C, by making it false) if and only if cause(s) is corrected (Point A status becomes false). When Point A is true (meaning none of the causes are corrected), correcting only the insufficient visibility condition won't affect collision. Correcting insufficient visibility together with correcting a cause(s) will aggregate the elimination of collision efforts. This way, the map logic properly reflects the aforementioned differences in conditions. Refer to Table 1 for the truth table.

Causes Status (Point A)	Insufficient Visibility Status (Point B)	Collision Event Status (Point C)
F	F	F
F	T	F
T	F	T
T	T	T

Table 1: Truth Table • Legend: T = True; F = False

Since correcting the insufficient visibility condition won't eliminate the failure in the future but only reduce its probability, it meets the definition of the *contributing factor* term (grey shaded block in Figure 1). On the other hand, building an overpass (thus making both cross-directional traffic and Point A status false) will physically guarantee avoidance of a collision. Of course, real life is not black and white. No one can guarantee with 100 percent certainty that, for instance, the absence of signal lights/automatic gates was a cause as opposed to a contributing factor. After all, some drivers may choose to break through the wooden gates. In the end, the fact is, it is up to the analyst to qualify a condition. In this particular case, the automatic gates also could be qualified as a *contributing factor*, but the key point is a condition has to be qualified one way or another based on its ability to prevent a failure. As far as a corrective action is concerned for this particular example, the analyst may or may not suggest, for instance, installation of a more robust metal gate. Ultimately, the solution should be driven by process/equipment criticality.

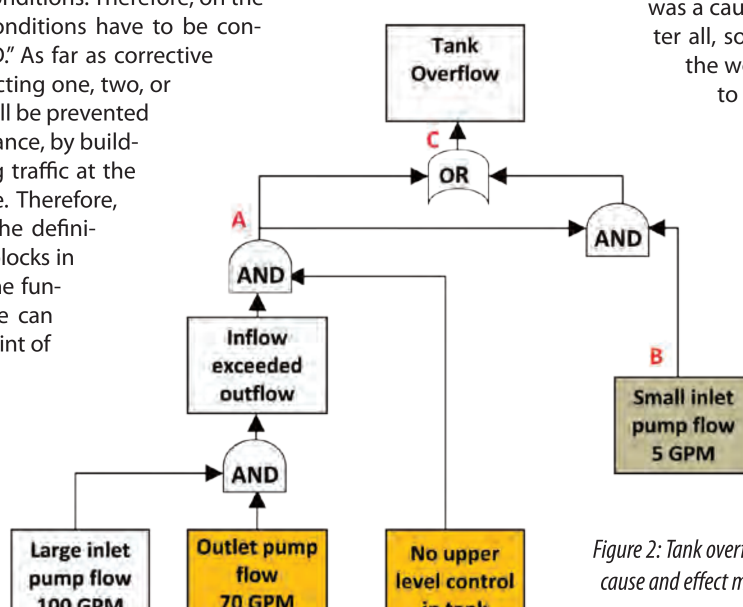

Figure 2: Tank overflow cause and effect map

Distinguishing a *cause* from *contributing factor* makes the cause and effect map more complex. To simplify it, one could connect all conditions – in this case, the three *causes* and *contributing factor* - with an "AND" gate and make a note that the visibility condition is a *contributing factor*. However this won't be correct from the formal logic perspective. Remember that the cause and effect map is a concise representation of the analysis path performed in the narrative portion by applying formal logic. It will be even fair to say that the narrative has limited capability of describing complex, multi-branched logic relationships between the conditions, whereas the map offers a clear and accurate view. When looking at the map, one should be able to determine clearly as to which condition or combination of conditions can eliminate the problem and which ones can't. As mentioned earlier, it is ultimately up to the stakeholders to decide which conditions they are willing to work on. If recourses are available, correcting a *contributing factor* also may be an option if proven to be cost effective.

Another example involving equipment operation will reinforce the approach expressed earlier. Picture a hypothetical system consisting of a relatively small waste tank with no upper level control. The large inlet pump is delivering Product #1 to the tank at a rate of 100 GPM, randomly when this product is available, and can't be changed. The small inlet pump is delivering Product #2 at a rate of 5 GPM, which can be reduced if needed. The outlet pump is taking the waste from the tank at a rate of 70 GPM. When the large inlet pump is not delivering the product continuously, the outlet pump is capable of pumping the waste out of the tank, but there are times when the waste tank overflows, which then constitutes a failure.

In this example, the causes of an overflow are determined as follows (yellow shaded blocks in Figure 2):

- Outlet pump flow at 70 GPM is low,
- No upper level control.

The formal logic reflecting the relationships between the conditions is shown in the form of a cause and effect map in Figure 2. In this case, no detailed explanation is required due to its simplicity, but in a more complex case, the narrative should contain a discussion on conditions and provide evidence, while the map should allow clear visualization of the conditions and their relationship.

The conditions in Figure 2 qualify as causes because correcting any of them or both, for instance, increasing the outlet pump flow rate to 105 GPM, will definitely prevent overflowing. On the other hand, the small inlet pump (grey shaded block) will only increase the likelihood of overflowing when working together with the large inlet pump. Reducing the small inlet pump flow rate won't guarantee elimination of the overflowing. Thus, it constitutes a *contributing factor*. Formal logic of the cause and effect map is clearly reflecting this fact, again, by employing a combination of "AND" and "OR" gates. As in the previous example, the formal logic demonstrates that correcting either one or both causes will eliminate tank overflow, whereas the small inlet pump flow reduction by itself can't eliminate the failure and will only reduce the likelihood of overflowing.

It is important to note that distinguishing between a *cause* and a *contributing factor,* as defined in this article, is a valuable concept from a corrective action perspective. The analyst must demonstrate which condition will definitively or most likely prevent the failure as opposed to which may only somewhat reduce the likelihood or consequences of a failure. The difference between a *cause* and a *contributing factor* should be properly reflected with formal logic in a cause and effect map.

Disclaimer: The views contained herein are the author's and are not attributable to the author's employer.

David Gluzman has over 25 years of experience in all areas of Reliability Maintenance Engineering, working in various industries. He is a Certified Reliability Engineer from ASQ, Certified Vibration Analyst Category IV from Vibration Institute, and holder of other CBM certifications. He is also an author of multiple publications in various trade magazines.

Electrical Motor Diagnostics at Romulus Engine Operations

Improved Reliability Through Electrical Motor Testing

Richard Scott

Electrical motor diagnostics (EMD) as practiced at Romulus Engine Operations includes off- and on-line motor testing. It also includes acceptance testing of new and repaired electric motors prior to storage or installation, tracking and correction of minor defects during the lifecycle of the system, tracking of issues related to the motor repair or new motor vendors, and route-based testing of critical motors.

Thousands of articles can be found about the subject of improving rotating equipment reliability and even more subject matter experts are available to industries worldwide. However, sustaining a predictive maintenance (PdM) program over a long period of time is elusive for many. Generally speaking, purchasing the hardware and software, and then obtaining the necessary training can be the easy part. What is really difficult is trying to maintain the program through a severe economic downturn, employment attrition within the plant, plant and union management changes, etc. In fact, what makes the story of Romulus Engine so interesting is how the plant has been able to not only sustain the program, but also expand it when so many others within the industry have cut back or even eliminated their EMD program.

This particular part of the story starts around 2006 with the implementation of a computerized maintenance management software system called Maximo. In 2007, a formal PdM team was formed and the initial focus was inspections using infrared thermography. During this time, the process and procedures for implementing the inspection process had to be developed from scratch.

The goal from the beginning was to develop a world-class program. In order to do that, a selection process had to take place to find the right people who were self-starting individuals who could work within the parameters of a team concept. Also, a salaried electrical engineer was tasked at the beginning to act as a technical and administrative resource. This person also acted as a "cheerleader" to get this new group of people to function like a team. In order to get to that point, they had to adopt a new way of thinking.

This new way included establishing a communication process within the plant to inform all departments and personnel of the various technologies to be used. A weekly meeting consisting of both salaried and hourly team members was implemented. In the beginning, the plant focused on setting up the program, which, as you can imagine, was a daunting task. The team had to "hash out" everything from what to test and what technologies to focus on, to what the report should look like? From this process came the work procedures and processes that drive the program today.

The initial hourly team consisted of Mike Anaple and Ken Breece from the first shift. In 2008, the PdM program was expanded to include EMD based on United Auto Workers/World Wide Facilities Group quality network planned maintenance (UAW/WFG QNPM). Establishing the EMD program also involved field trips to motor vendors, other facilities doing motor testing, seminars and networking with subject matter experts. Later in 2008, a second shift team was added, consisting of Sam Richardson and Mike Nault. Key support from the salary side came from Electrical Engineer Cheryl Murphy, plus strong support from plant management.

As the program exists today, it consists of infrared, ultrasound, EMD and vibration. Of these four technologies, infrared and EMD are the most

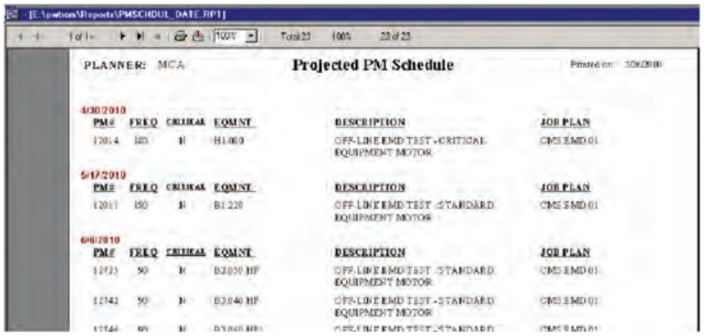

Figure 1: Maximo software PM schedule report

DATE	AREA	EQUIPMENT #	DESCRIPTION	WORK ORDER #	POTENTIAL CATASTROPHE	REPAIR TIME IN HOURS	PROACTIVE SAVINGS	TECH USED
1/14/11	WFG	WASTE WATER PUMP	OVERLOAD TRIPPING INTERMITTENTLY	551312	MOTOR FAILURE/DOWNTIME	0.5	$7,500.00	EMD OFFLINE
3/2/11	WFG	ROOF FAN 49	MOTOR BLOWING FUSES, MAIN RUN GROUNDED	668844	UNNECESSARY MOTOR OR STARTER REPLACEMENT	0.75	$11,250.00	EMD
3/28/11	WFG	AIR HOUSE 41	MOTOR BLOWING FUSES	676458	MOTOR GROUNDED / REPLACED MOTOR	1	$15,000.00	EMD
3/29/11	WFG	AIR HOUSE 41	TEST NEW MOTOR BEFORE PLACED ON ROOF AND INSTALLED	676458	MOTOR INSULATION BROKEN DOWN / GET ANOTHER MOTOR	0.5	$7,500.00	EMD
7/21/11	WFG	AC-1	CHECK SUPPLY MOTOR	704230	IDENTIFIED BAD FAN MOTOR CAUSING FUSES TO BLOW	0.75	$11,250.00	EMD
8/9/11	WFG	RETURN FAN #1	SOFT START HAD CATASTROPHIC FAILURE, CHECK MOTOR FOR INTERNAL DAMAGE	712917	UNNECESSARY MOTOR REPLACEMENT	0.5	$7,500.00	EMD
8/15/11	WFG	RETURN AIR #4	MOTOR BLOWING FUSES AT BUS, CHECK MOTOR	714814	UNNECESSARY MOTOR REPLACEMENT	0.5	$7,500.00	EMD
10/14/11	WFG	AC UNIT ABOVE V8 CAFETERIA	CHECK MOTOR FOR AC GUYS. VFD IS BAD BUT WANT TO MAKE SURE MOTOR IS GOOD	726543*	UNNECESSARY REPAIR AND FURTHER DAMAGE	0.75	$11,250.00	EMD
11/17/11	WFG	PUMP HOUSE	PUMP # 10 FUSES BLEW AND OVERLOAD TRIPPED	729154	UNNECESSARY MOTOR REPLACEMENT	0.5	$7,500.00	EMD
11/17/11	WFG	POWER HOUSE	AIR CHILLER #2 BLEW FUSES DID OFFLINE AND ONLINE TEST	729155	UNSCHEDULED DOWNTIME	1	$15,000.00	EMD
11/17/11	WFG	MC-150 NORTH	BLOWING FUSES	728067	VENTILATION SYSTEM DOWN	0.5	$7,500.00	EMD

Figure 2: Maximo is used to track cost avoidance

widely used. Ultrasound was expanded in 2010 and they expect to expand the vibration program this year.

Specific to EMD, this includes route-based testing of critical production equipment, request-based work (which can include both production and facilities equipment), testing of motors before and after repair, testing of new motors and shaft rotation of motor spares. Tracking of motors sent in for repair require that a process be established with the commodity manager so the information is available within their computer system.

The electrical motor diagnostics testing program has generated significant cost avoidance savings over the years and is considered to be a pillar in their Predictive Maintenance (PdM) reliability testing process.

EMD as practiced by Romulus Engine includes both on-line and off-line testing of motors. On-line testing using electrical signature analysis (ESA) is performed mostly on AC induction motors with off-line testing using motor circuit analysis (MCA) for AC induction and DC motors.

Some of the benefits of the EMD program include reductions in troubleshooting time, motor repair shop "no problem found" reports and severity of rotating machinery failures. Overall predictive maintenance cost avoidance for 2011 was over $3 million and EMD accounted for ~22 percent of this amount. Infrared inspection leads the savings at ~45 percent. Vibration and ultrasound, along with high-speed video camera analysis, make up the balance.

The team is required as a department to report program results on a quarterly basis as part of the QNPM guidelines. Reporting out includes sharing any new information on emerging technologies, cost avoidance and any significant finds. Sharing this information plant-wide brings greater awareness about the program and builds a level of trust in the PdM teams' equipment and knowledge. It is a constant learning process for everyone in the plant.

Another aspect that has proven to be important to sustaining the program is sharing information within the team. As an example, if one of them has an issue not seen before in a particular motor, they have each other's cell phone numbers so they can communicate even when off shift. In the beginning, all of this was brand new, so everyone had a steep learning curve and sharing of information proved to be very important to creating a successful program.

With respect to the PdM program, route-based testing follows this basic structure:

- Routes are generated using Maximo software.
- Monthly route sheets are used to perform PdM testing for infrared, EMD, vibration and ultrasound.
- As a route is completed, information is entered into Maximo.
- If follow-up work is generated, then a Maximo work order is created along with appropriate information to fix the problem.
- Area trades complete required work.

• The work order is returned to the PdM department so they can perform a follow-up test (retest).

• If the test comes back good, then this information is discussed with the appropriate tradesperson (creates program awareness and continuous improvement).

• If retest fails, then a corrective work order is issued to the area.

Request-based testing follows this basic structure:

• PdM team member is dispatched to investigate possible machine or process issue.

- Maximo work order is generated.
- PdM department determines if issue can be solved using appropriate equipment (infrared, EMD, vibration, ultrasound, etc.).
- If a problem is detected using PdM equipment, then a follow-up corrective work order is generated to complete any issue found.
- If no issue is found, then work order is closed out.

Maximo is used to track and report cost avoidance using a conservative calculation process. As previously mentioned, this information is shared plant wide.

For those new to EMD, here are a few examples that illustrate program savings.

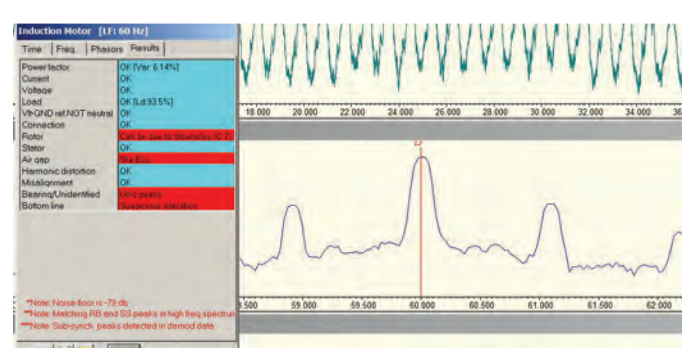

Figure 3: On-line testing ESA software analysis screen

Motor Troubleshooting Process

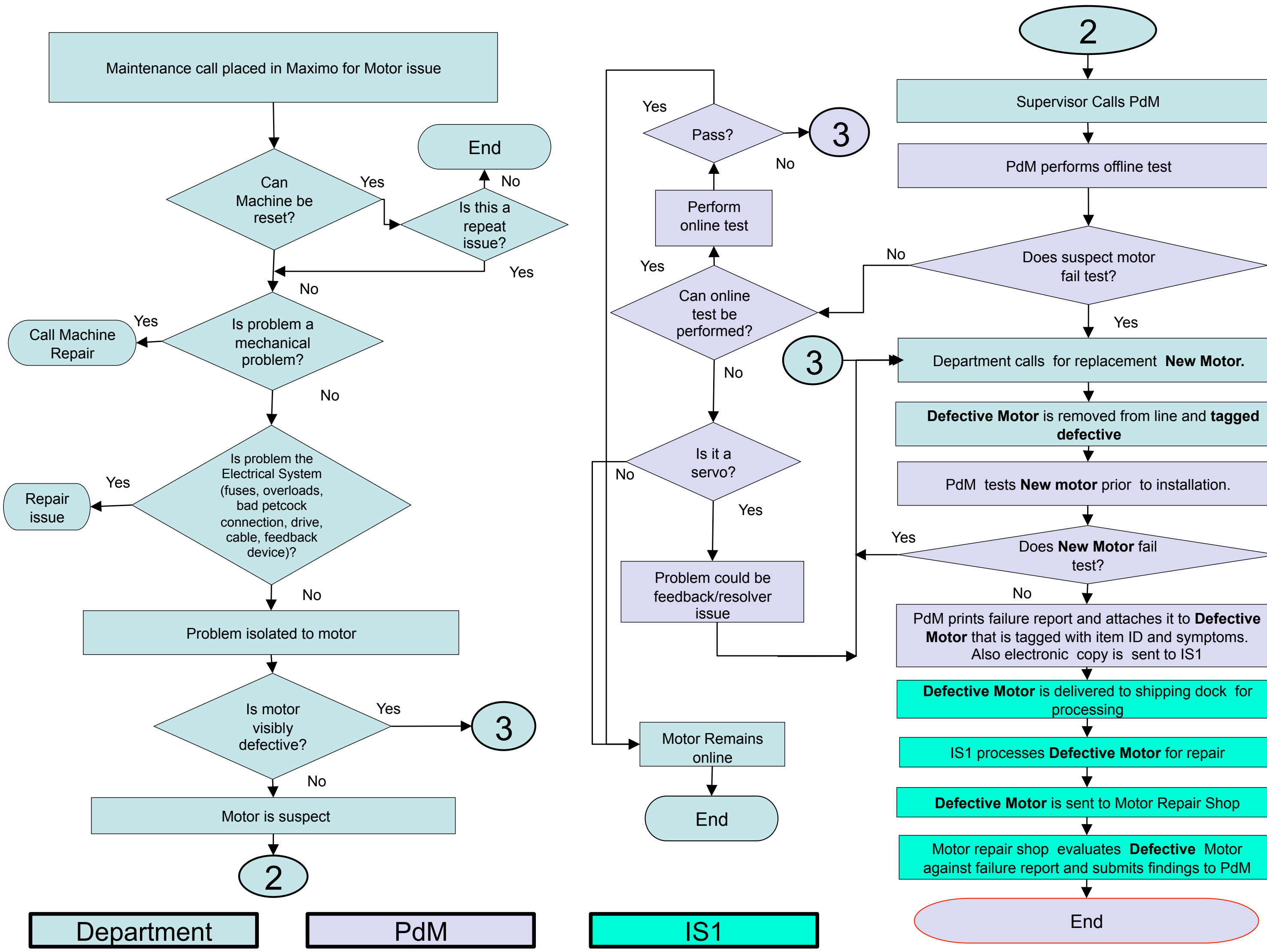

Figure 4: PdM team troubleshooting process

EMD off-line testing incoming inspection find: Ash house 60 HP motor located on a roof failed and a replacement was brought in. As part of the EMD testing program, the motor was tested prior to starting the installation process. Results from the motor circuit analysis (MCA) test showed the motor was in poor condition. A second motor was brought in and tested. This one tested okay, so installation was completed. Since this motor was located on the roof, installation required the use of a lift truck, elevator, block and tackle, and between six to eight hours of labor. The cost avoidance by not installing a new motor with a defect is ~$20,000. Incoming motor testing has increased rotating equipment reliability and the test itself only takes a few minutes.

EMD on-line testing find: This is a 60 HP pump system motor that is tested every six months. Routine testing detected a rotor fault and the motor was replaced during an off shift (normal production shutdown). The report from the motor shop showed cracked rotor bars and a blow hole in the end ring. Cost avoidance by replacing the motor before it failed during a production cycle was $142,500 for the supply pump. Figure 3 is a snapshot of the ESA software analysis screen.

Motor troubleshooting: EMD, along with other testing technologies, are used for troubleshooting a motor system that is running poorly or has failed. Figure 4 is the structure that Romulus Engine developed.

Creative testing using MCA: This plant has many AC motors that include a coil activated brake. Diagnosing problems with the brake in the past was a problem. Since these brakes are a three-phase device made up of coils, Romulus Engine Operations uses the MCA test instrument to determine the electrical condition of the brake. No more guessing whether the problem is electrical or mechanical in nature.

Romulus Engine Operations has a successful and sustainable EMD program that has thrived when others in the industry have either reduced the scope of their EMD program or eliminated it entirely. The EMD testing program has generated significant cost avoidance savings over the years and is considered to be a pillar in their PdM reliability testing process. After interviewing team members, it is apparent that it is the people involved at all levels in the plant that has made the difference. As one team member stated: "To have a world-class PdM program is what we strive for."

About Romulus Engine Operations

Romulus Engine is located in Romulus, Michigan, and employs nearly 800 people. Hourly employees are represented by UAW Local 163. The plant produces a variety of V6 and V8 engines that power GM full-size SUVs and pickups, including the Chevrolet Express, Silverado, Tahoe, Avalanche, Suburban and Colorado, GMC Savanna, Sierra, Yukon, Envoy and Canyon, and Cadillac Escalade. Romulus-built engines are also used for marine and industrial applications. Over 477,000 engines were produced in the 2011 calendar year. Historically, the plant has a long-standing reputation for quality, productivity and performance.

Instruments used in their PdM program:

Infrared: FLIR P640, P60 and T400; Ultrasound: UE Systems Inc. 10000 Ultraprobe; Vibration: CSI 2130; EMD: off-line ALL-TEST PRO ATIV and on-line ALL-TEST PRO ATPOL II.

Romulus PdM team members are left to right: Michael Nault, Mike Anaple, Cheryl Murphy, Sam Richardson, and Ken Breece.

Mike Nault *has been a journeyman Electrician at GM since 1995 and doing Predictive Maintenance since 2008. He has completed Level I and Level II Infrared Thermography. He also has Level I Electric Motor Diagnostics and Ultrasound training.*

Mike Anaple *has been involved in Predictive Maintenance since 2007, focusing on Infrared (Level III), EMD, Ultrasound and Program Management. He has almost 25 years of Industrial Electrical Maintenance experience in various capacities.*

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Asset Condition Management Ir infrared thermal imaging

CASE STUDY

Using IR Windows to Monitor Communications on Critical Motors

IMC 2012! Conference Speaker

Nate Maughan and Tim Rohrer

Kennecott Utah Copper Mine

In 2011, the concentrator facility at Kennecott Utah Copper Mine installed infrared (IR) windows on the motor access doors of critical DC motors to monitor the commutator and brushes. The results of direct access to thermographic data made possible by the use of IR windows has been improved safety and better, more complete data with regards to the health and efficiency of those motors.

Background:

Kennecott Utah Copper Mine (KUC) is fully integrated, from extraction and concentrating to smelting and refining. It is part of the Rio Tinto family of mines. At over 100 years old, the mine has produced more copper than any other mine in the world. It is currently more than 2.7 miles across and roughly 0.75 miles deep, making it the world's largest human excavation on earth. In fact, if you stacked two Sears Towers on top of each other at the bottom of the mine, they would still not make it to the top of this mine.

More than 150,000 tons of ore is moved via conveyor from the mine to the Copperton Concentrator facility every day for processing. The first

stage of processing in the concentrator is the semi-autogenous grinding (SAG) mills. The SAG mills pulverize the ore into smaller particles. As the dual, 6000 horsepower motors rotate the drum, a series of lifting plates built into the walls of the drum repeatedly lift weighted balls and chunks of ore along the sides of the drum and drop them back onto the ore at the bottom of the drum. This grinding process is critical to extracting the copper from the ore in later steps.

The concentrator's grinding operation operates 24 x 7 x 365. So uptime is critical and any unplanned downtime reduces the facility's potential throughput to the smelter and refinery.

Between 2007 and 2011, Kennecott Utah Copper replaced three SAG mill motors. Each motor requires up to five days of downtime to replace.

The cost for the monitoring processes is viewed throughout the organization as a worthwhile investment that pays dividends by preventing losses.

In addition to the financial implications, potential failure of these assets also represents a safety risk to personnel involved in the process when the failure occurs, and to the maintenance personnel tasked with swapping the motors out.

Due to the critical nature of the SAG mill motors and because they are so labor-intensive and costly to replace, KUC's predictive maintenance

Grind Floor at the Copperton Concentrator

Of the six SAG mill motors, three are over 20 years old. The combination of age and criticality of the equipment makes proactive condition monitoring imperative for site profitability.

team utilizes a suite of monitoring and maintenance techniques to keep the motors running at peak efficiency. The cost for the monitoring processes is viewed throughout the organization as a worthwhile investment that pays dividends by preventing losses.

Problem Faced:

Of the six SAG mill motors, three are over 20 years old. The combination of age and criticality of the equipment makes proactive condition monitoring imperative for site profitability.

Condition monitoring technologies utilized in SAG mill motor monitoring included:

- Continuous monitoring of motor temperature (via RTDs), motor current, airflow, and water flow rates.
- Vibration and ultrasonic are monitored periodically and trended over time to spot developing changes.

One aspect of motor health that had been a contributor for motor failures was brush wear. But the commutator block that houses the brush assembly is not transmissive to infrared radiation. Safety and practicality prevent the removal of the commutator housing during operation. Therefore, the brushes are not accessible for direct line of sight infrared imaging and wear monitoring. As a result, KUC was missing this critical equipment health data point and needed to develop a safe and efficient manner of inspecting the commutator and brushes.

Between June and October 2011, KUC installed two Exiscan XIR-S-4 series IR windows on the motor access doors of six SAG mill motors. Inspections are performed by KUC thermographers every nine weeks (or more frequently as requested). Within the first two months, the windows en-

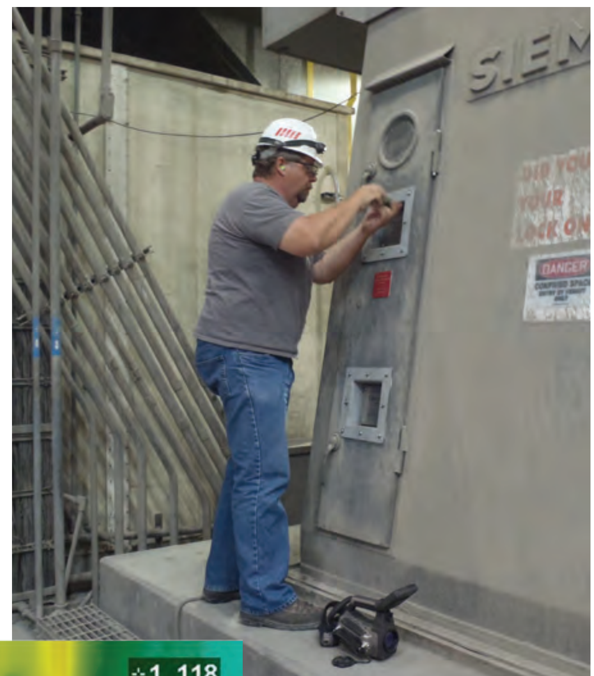
The ability to inspect the SAG mill motors with infrared monitoring through IR windows is generating a short term return on investment (ROI).

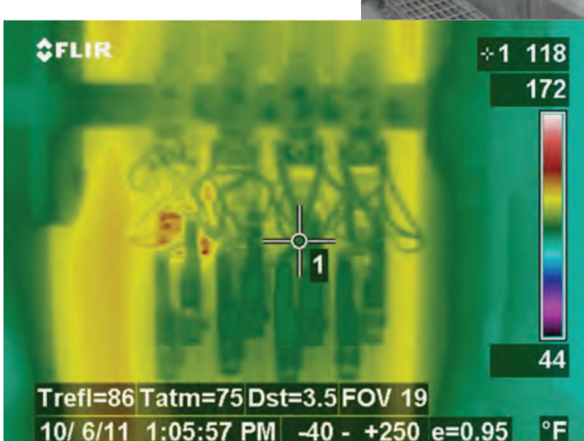
abled KUC's predictive maintenance staff to gather accurate motor temperatures, which have helped the maintenance staff improve the operation and efficiency of the motors.

Results:

Case 1:

The PLC indicated that an RTD on motor #6 was running higher than normal. It was thought the RTD was out of calibration and the temperature reading was inaccurate. A thermographer was sent out to inspect the motor. An external scan of the motor did not reveal a significant difference in temperature. However, an infrared analysis of the inside of the commutator, via inspection through the IR window, confirmed the RTD's higher temperature measurement and confirmed that steps should be taken to bring the temperature of the motor back into specification.





Case 2:

Spring pressures and brush seating have been issues in the past on the SAG mill motors. Infrared inspections through the IR windows identified brush seating issues before much damage could be done. The results of these saves have been:

- More reliable and predictable equipment operation.
- Improvement in asset management.
- Maintenance cost savings: rebuild of the motor after a failure of brush assemblies would typically run $300k-$500k in parts and labor, plus the potential seven to 10 days of unplanned outage resulting in millions in lost opportunity costs.

Economic and Safety Benefits of Inspection via IR Windows

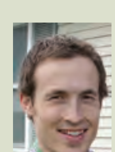
The ability to inspect the SAG mill motors with infrared monitoring through IR windows is generating a short term return on investment (ROI). Early identification of commutator and brush anomalies has enabled KUC maintenance staff to fix minor issues more cost effectively and efficiently than if those issues had progressed to the point where they would have been picked up by other technologies. The long-term prevention of unplanned, catastrophic failure on these critical motors is expected to generate further ROI on the $20k investment in infrared windows.

KUC also anticipates an improvement in safety as a result of using infrared inspection through IR windows by:

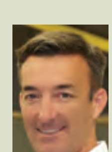
- Eliminating or reducing equipment failures by reducing the amount of change-out, rebuild and repair work. Consequently, the reduction in these activities will reduce risks to personnel who would otherwise be charged with the various stages of repairing or replacing those assets (electrical, mechanical and transport tasks at every stage).
- Reducing the risk of failures also reduces the related safety risks to personnel who might be in the proximity of the failure when it would have occurred.
- Eliminating the high-risk tasks associated with opening the motor cabinet. In fact, the practice of inspection through an open panel is prohibited at KUC due to the obvious safety concerns.

Conclusion

The SAG mill motors are so critical to Kennecott Utah Copper Mine's 24x7 processes and are extremely labor-intensive and expensive to change out in the event of failure. Installing IR windows to monitor the commutator and brush assembly during operation has allowed thermographers to safely and efficiently gather a critical data point that will help protect SAG mill motors from unplanned and catastrophic failures. In fact, use of the IR windows has helped KUC's predictive maintenance staff identify some minor problems that were easily corrected within the first few months of use and are anticipated to help KUC maximize uptime of its Copperton concentrator processes.



Nate Maughan is a Maintenance Engineer at Rio Tinto's Kennecott Utah Copper Mine in the Copperton Concentrator facility. Nate received his Mechanical Engineering degree from Brigham Young University, Idaho and has been previously published in SAE International for research work completed at a former employer. www.Kennecott.com



Tim Rohrer is the President of Exiscan, LLC, manufacturer of infrared and visual inspection windows. Tim is a Level 2 Thermographer, with a decade of experience in the Predictive Maintenance industry. Mr. Rohrer sits on several industry standards committees. He has had technical papers published in industry journals, and has been a presenter at industry conferences, workshops and similar events. www.Exiscan.com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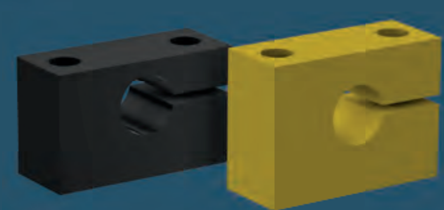

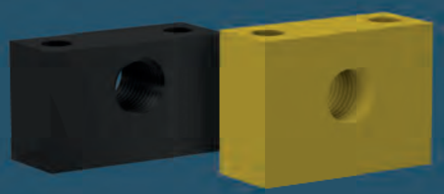

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Part 1 Precision Gear Lubrication
Building a Foundation for Reliability

IMC-2012! Conference Speaker

Mark Barnes

Introduction

Gears are commonplace in many different industries. From high speed gearing found in turbo-machinery to slow speed gear reducers found across a multitude of manufacturing and process industries, gears are the workhorses of industry. Yet despite their widespread use, gears are perhaps the least maintained of all lubricated components. This can result in poor reliability, excessive maintenance and repair costs, and unscheduled production downtime.

The problem has become even more pronounced in the last decade. While many years ago gears were oversized and capable of withstanding a degree of use and abuse, today's gear drives are precision components with higher power densities requiring a greater focus on lubrication.

In this multipart series, we'll examine the factors that impact precision lubrication in industrial, including lubricant selection, application and contamination control, as well as how to develop precision lubrication practices for enclosed gears.

Lubrication Fundamentals for Gear Drives

From a lubrication perspective, gears can be categorized based on their design (gear geometry), speed and load. For high speed gearing, surfaces are separated by a full oil film (hydrodynamic or elasto-hydrodynamic lubrication). Slow turning and/or heavily loaded gear drives tend toward boundary lubrication where point loading can result in surface separation between gear teeth that is equal to or less than the mean surface roughness of the mating gears (boundary lubrication). Table 1 gives a general overview of common gear types and the type of lubrication film expected under different loads and speed.

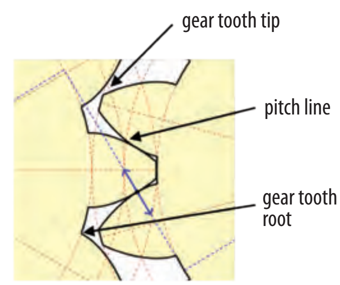


Figure 1: Meshing spur gears with involute gear tooth profile

In most gears, the frictional force between the gear teeth is typically a combination of sliding and rolling friction. The degree of sliding versus rolling friction, in conjunction with the speed of rotation and applied load, all factor into how the meshing surfaces engage and ultimately how effective the lubricant is in reducing mechanical wear.

To illustrate this point, consider one of the simplest of all gear designs: a spur gear with involute gear tooth profile (Figure 1). For the sake of discussion, we can consider two points of interaction between the meshing gear teeth: the tip to root contact and the pitch line contact.

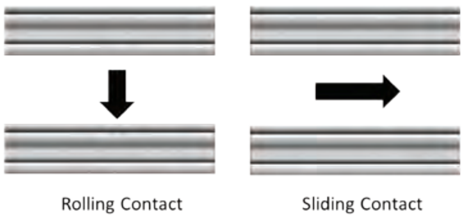
In an involute spur gear design, such as that shown in Figure 1, the contact at the pitch line on each gear set is almost exclusively rolling friction. Rolling friction is defined by two surfaces that approach each other in a perpendicular direction (Figure 2a). Under rolling contact conditions, separation between the moving surfaces will depend on the applied load and speed. At higher speeds, the increased pressure on the lubricant under load causes a rapid increase in viscosity of the fluid. With sufficient pressure, the lubricant can undergo an instantaneous phase change from liquid to solid, which, in turn, can result in an elastic deformation of the mating machine surfaces. Elastic surface deformation results in the load being dissipated across a larger surface area, allowing the gears to transmit the applied load without mechanical wear as the surfaces are separated by a full oil film. This is an effect referred to as elasto-hydrodynamic lubrication (EHL). The key to effective elastohydrodynamic lubrication is having a lubricant with sufficient viscosity and a high viscosity pressure coefficient. Having too low a viscosity or poor viscosity pressure coefficient can result in metal-to-metal contact, dramatically reducing the life expectancy of the gears.

Gear type	Dominant Frictional Force	Low Speed (<100 RPM)		High Speed (>1000 RPM)	
		Pitch line	Tip/Root	Pitch line	Tip/Root
Spur	More Rolling ↑ / More Sliding ↓	Boundary	Boundary	Elastohydrodynamic	Hydrodynamic
Straight Bevel		Boundary	Boundary	Elastohydrodynamic	Hydrodynamic
Herringbone		Boundary	Boundary	Elastohydrodynamic	Hydrodynamic
Helical		Boundary	Boundary	Elastohydrodynamic/ Hydrodynamic	Hydrodynamic
Spiral Bevel		Boundary	Boundary	Elastohydrodynamic/ Hydrodynamic	Hydrodynamic
Hypoid		Boundary	Boundary	Elastohydrodynamic	Hydrodynamic
Worm		Boundary	Boundary	Elastohydrodynamic	Hydrodynamic

Table 1: Typical lubrication regimes found in gears

For lower speed gears under rolling friction, the rate at which the two surfaces approach is too slow to allow the EHL film to form. Under these conditions, boundary lubrication will occur, requiring the use of extreme pressure and anti-fatigue additives to prevent wear from occurring.

By contrast, at the tip to root of an involute gear tooth profile (Figure 1) and in many other gear geometries, sliding friction is the dominant frictional force. Sliding friction involves surface motion in a parallel direction (Figure 2b). In high speed gearing, the speed relative to the load is typically high enough that moving surfaces are separated by a full film of oil. However, unlike rolling friction where elastohydrodynamic lubrication is the norm, high speed sliding friction results in hydrodynamic separation



Figures 2a and 2b: Rolling and sliding contact between two friction surfaces

between the moving surfaces, an effect akin to a water skier experiencing "lift" once the tow boat speed is high enough for the applied load (weight of the skier and water ski dimensions). Hydrodynamic lubrication requires the oil to have sufficient viscosity for the applied load and speed, both of which have an impact on oil film thickness.

For slower turning gears, such as the low speed gear in a gear reducer, the viscosity of oil necessary for hydrodynamic lift is too high compared to the ability of the oil to flow into the load zone. As a result, a hydrodynamic oil film cannot be maintained and, once again, boundary lubrication conditions dominate. Where boundary lubrication occurs in conjunction with sliding motion, severe sliding wear – sometimes referred to as adhesive wear, galling, or scuffing – can occur. In an involute gear geometry, this typically occurs just above and below the pitch line and frictional forces transition from pure rolling to sliding friction.

Sliding motion also results in higher localized temperatures, which causes a reduction in the oil's viscosity and can also cause the oil to be wiped away from the converging gear surfaces, further inhibiting the formation of an oil film. Under these circumstances, the meshing gears will be under boundary lubrication conditions. Where boundary lubrication is anticipated, special wear prevention additives must be used to protect gear teeth.

Gear Oil Lubricant Selection

Lubricants used in gearing come in three basic classes:

- Rust and oxidation (R&O) inhibited oils
- Extreme pressure (EP) oils
- Compounded (COMP) oils, sometimes referred to as cylinder oils

The type of lubricant used will depend on the type of lubrication regime (hydrodynamic, elastohydrodynamic, boundary, etc.) and the type of gear set. For higher speed application where full film conditions exist, simple rust and oxidation inhibited oils are used. Aside from their lubricating properties, these oils need to exhibit good oxidation resistance to counter the effects of the heat generated and good corrosion resistance to counteract the effects of any ambient moisture ingress and protect any yellow metals that may be present.

For slower speed or higher loaded gears where full film separation is simply not possible, extreme pressure additized gear oils should be used. There are several different types of EP additives, from chemical films that react with and coat the gear surfaces to solid suspensions that improve lubricity under sliding contacts. However, all have the same basic function: to reduce the coefficient of friction under boundary lubricating conditions.

For worm gears in particular, it is often recommended to use a compounded oil rather than an EP additized oil. The reasons for this are twofold. First, some chemically active EP additives can be corrosive to yellow metals (brass, bronze, etc.), which are commonly used for the ring gear in worm drives or in bearing cages. Second, compounded oils contain lubricity agents based on fatty materials that do a better job of reducing the coefficient of sliding friction, the dominant frictional force in most worm drives. For gears containing yellow metals, chemically active EP additives are not recommended at elevated temperatures (140 F-150 F and higher).

Like any other lubricant application, viscosity is the single most important decision when selecting a gear oil. Viscosity is selected based on the speed and size of the gears by calculating the pitch line velocity and the ambient operating temperatures. While this is a good starting point, other variables, such as shock loading or cold ambient start-up conditions, also must be factored in for an optimized lubricant selection. Viscosity mismatch is one of the most common errors with gearbox lubrication. Table 2 provides some good general guidelines on viscosity selection.

Oftentimes, OEM recommendations are adopted in selecting the correct gear lubricant. While this is an excellent practice in many applications, where extreme conditions, such as high or low operating temperatures or shock loading, are present, OEM guidelines should be considered as just a starting point and should be adjusted up or down depending on the application.

Temp °C	Pitch line velocity, m/s[3)]							
	1.0 - 2.5	2.5	5.0	10.0	15.0	20.0	25.0	30.0
10	32							
15	46	32						
20	68	46	32					
25	68	46	32					
30	100	68	46	32				
35	100	100	68	46	32			
40	150	100	68	46	32	32	32	
45	220	150	100	68	46	46	32	32
50	320	220	150	100	46	46	46	32
55	460	220	150	100	68	68	68	46
60	460	320	220	150	68	68	68	46
65	680	460	320	220	150	100	100	68
70	1000	680	320	220	150	100	100	68
75	1500	680	460	320	220	150	150	100
80	2200	1000	680	460	220	220	220	150
85	3200	1500	1000	460	320	220	220	150
90	3200	2200	1000	680	460	320	320	220
95		3200	1500	1000	460	460	320	220
100		3200	2200	1000	680	460	460	320

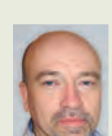
Table 2: Recommended viscosity grade for enclosed gears based on the pitch line velocity of the slower speed gear and operating temperature

In some instances, such as high or low operating temperatures or the desire to extend oil drain intervals, the use of high performance gear oils, including synthetics, is recommended. Where their usage can be financially justified, these lubricants offer significant benefits in low temperature start-up, high temperature thermal and oxidative stability, and improvements in film strength. Although there are several different types of synthetic gear oil, the two most common are poly-alpha-olefin (PAO) and poly-alkylene glycol (PAG). Both have their relative merits, but their use should be considered judicially since the cost of switching to a synthetic gear oil can often far outweigh the benefits. When selecting synthetic gear oil, it's not uncommon to drop down one ISO viscosity grade from the OEM recommendation since the effective viscosity of a synthetic gear oil at elevated operating temperatures often matches that of the OEM recommended mineral oil grade due to the higher viscosity index of synthetic fluids.

Increasingly, PAG fluids are being used in gearboxes, including initial factory fill. While these types of lubricants offer some distinct advantages, including lower coefficients of sliding friction and better deposit control, care must be exercised when using PAG fluids since they are chemically incompatible with hydrocarbon fluids, including conventional mineral-based gear oils and PAO synthetics.

Summary

While lubrication selection is an important first step in ensuring gearbox reliability, equally important is how the gearbox is maintained throughout its life. The degree to which water, moisture and other contaminants are controlled, as well as the introduction of precision maintenance practices, such as basic inspections and oil analysis, impact the longevity and performance of in-services gearboxes. In Parts 2 and 3 of this series, we'll examine how to ensure gear drives in your facility continue to operate reliably and efficiently.



Mark Barnes, CMRP, is Vice President of the Equipment Reliability Services team at Des-Case Corporation. Mark has been an active consultant and educator in the maintenance and reliability field for over 17 years. Mark holds a PhD in Analytical Chemistry. www.descase.com

Wolf Pack Maintenance

Taking the Team Approach to Meet Your Goals

Michael Rezendes

Many companies today are jumping on board for the latest and greatest "flavor of the month" when it comes to getting the job done as a team. There is no shortage of experts more than willing to step in and guide your company on how to make sure your team is the best, with success all but assured if you follow their process. I'm certainly no expert in the field, but I believe a common sense approach that leverages real lessons learned from the past — a tribal knowledge, if you will — enforced by a wolf pack hierarchy is the way to success. A wolf pack approach understands the strengths and weaknesses inherent in any teaming situation and leverages that understanding to meet team goals.

Throughout the history of man, teams have been out there getting the job done. In conducting research for this article, I noted a similarity between group hunting methods used by man and the animal kingdom. One of the best examples of animal pack hunting is the gray wolf. Within the pack, there is the alpha wolf or team lead. This wolf guides the pack and makes sure the other wolves in the pack work as one to track and kill their prey. All the wolves in the pack know that unless they work together and succeed, no one will eat and ultimately not survive. Now we look at this example and relate it to early man. Since group hunting is common to many cultures all over the planet and there were no "hunting consultants" traveling to far off lands to instruct early hunters on the newest methods, then we must assume that early man may have learned from observing other species as they hunted. Aided by their growing intelligence, our hunting party quickly learned the advantages of working as a team so all could survive. Each hunter understood the rules and their individual roles and responsibilities.

Anyone who has ever been a member of any kind of team knows that the personal dynamics of a team play a huge part in their success.

Now flash forward 10,000 years and see how our maintenance "wolf pack" meetings discuss strategy. The prey is now known as uptime. The job at hand is ensuring that the company or "village" survives, with this task in the hands of the maintenance team.

Anyone who has ever been a member of any kind of team knows that the personal dynamics of a team play a huge part in their success. I believe this aspect of team dynamics is the Achilles' heel of the maintenance team. The formulation of the team can be comprised three different ways: individuals who are unknown to each other; individuals who are familiar with each other; or a combination of the first two scenarios. Examining the team dynamics of the first group, we have a team leader who is assembling the group and needs to be cognitive of the fact that he or she is acting as the alpha figure and may actually have one or more alpha type individuals being added to the newly formed team. In nature, the alpha pack lead leader would be physically challenged by the other alpha member for leadership rights to the pack. Obviously, we cannot have our first team meeting ending in a fight, so this is where the intelligence factor comes into play. The team lead should take the time to make sure all the members of the team know the team rules and their individual responsibilities. An effort must be made to ensure that everyone understands that individual viewpoints and ideas are welcomed and encouraged, but the team lead has the final authority.

In examining our second team dynamic scenario, we find that since team members know each other, they may bring preconceived opinions about their fellow team members. It is important not to dismiss these opinions entirely because some may very well be true. We carry many variables that make up who we are as people (traits, habits, enthusiasm, drive, etc.). How this life experience is managed is a crucial component that can either build value into a team or ruin it. The range may go from the young person just out of school who believes he or she "knows it all" to the experienced worker who has "seen it all" to everyone in between. In this scenario, it is important for the team lead to accentuate these differences and turn them into a strong and positive aspect of the team. The younger worker needs to know that he or she can learn a lot from the older worker by the way of tribal knowledge and the older worker needs to understand that there may be new methods and ways of doing things that he or she should be open to trying. Both types of team members need to realize that their very survival depends upon their mutual understanding. Even more importantly, each should understand that their individual contribution or role is vital to team survival and success.

Now that a maintenance team has been assembled, the team lead needs to ensure that the aspect of personal responsibility is at the forefront of the team's success. Each team member must remember that just as the members of a tribe or wolves in a pack may starve to death without the ability to act as one cohesive unit to procure food to ensure their survival, team members must also accept their individual responsibilities and work as one with the team to make sure they will continue their employment through the success of their company.

We've gone through the years and witnessed that nothing really ever changes with regards to our survival. The settings and circumstances of our human existence may have changed, but the core tenant of survival is still the driving factor that gets us all out of bed in the morning. We have gone from carrying a spear to hunt for food or a gun to hunt for dinner to carrying a toolbox and a cell phone on our hip to allow us to complete a maintenance action that provides the money needed to buy our groceries. Let us always look back to the past to help us guide ourselves to the future. The lessons of the past, whether good or bad, must always be remembered for us to learn and not be doomed by allowing history to repeat itself and, in turn, endangering our very survival.

Michael Rezendes is currently employed at Raytheon Technical Services Company. During his 37-year career at RTSC, he has gained experience in everything from production and test; to field service work with Navy equipment installations and maintenance development.

Reliability Engineering for Maintenance

Re reliability engineering

Maximize Intrinsic Reliability Through Focus in Early Project Phases

Mohammad Naseer Uddin

Inspired by the June 2012 article by Robert DiStefano in Uptime® magazine on the importance of implementing a reliability program in the early lifecycle of a project, I would like to share a few examples from real-life scenarios. My contention is by having a proper reliability program in place, many of these avoidable defects could have been eliminated during the early phases of the project, thereby delivering higher asset reliability at a lower lifecycle cost (LCC).

Case 1 – Parallel running of pumps to meet the designed throughput

A new mid-size refinery in the Middle East required parallel running of main condensate feed pumps (2x100%) during the commissioning phase to meet plant throughput, instead of having one on standby. The reason being that the motors driving the centrifugal pumps were getting tripped on high current overload when run individually at the designed throughput capacity. Running the plant on a single feed pump accounted for a 20 percent reduction in production. An early investigation by the project commissioning team and pump OEM recommendations (in absence of a reliability program) did not reveal the actual cause of the problem. Due to production pressures, it was mutually agreed to run both pumps in parallel to achieve the production targets until the problem was fixed.

Figure 1: ARV brought to workshop for overhaul

Figure 2: A seized ARV bypass valve

(Source: ARV valve from a Middle East refinery)

Both pumps ran in parallel for four years until a reliability section was established in the organization and conducted an investigation on parallel running pumps. The performance testing and design review of both pumps showed nothing significant. A second performance test was conducted to evalute the performance of automatic recirculation valves (ARVs) installed in the discharge lines of the pumps. It revealed extensive recycle flow across the ARVs, eventually shifting the system performance curve and causing the motors to trip at overload when run individually.

The ARVs were overhauled during the next available shutdown and both were observed to have seized slide valves, allowing full flow bypass across the ARVs since commissioning. This raised questions regarding the execution of ARVs' functionality checks prior to installation, as per vendor recommendations. After servicing, they were put back into operation and worked satisfactorily. Since then, one pump is now on standby.

Lifecycle cost savings of $800,000 was achieved by this defect elimination. The estimated production loss in the past four years due to the occasional downtime of one pump was estimated to be $350,000.

Similar problems were resolved on eight other pumps (with ARVs) that were running in parallel since commissioning with no standby, thereby saving millions in LCC costs in comparison to keeping them running in parallel for the lifecycle.

Lessons learned:

A reliability program in the early project phases could eliminate avoidable defects and deliver higher uptime performance at lower costs.

Emphasis should be given on proper acceptance testing and fixing equipment defects prior to the hand over to operations.

Always check the functionality of accessory items (e.g., ARVs, etc.) prior to installation as per OEM recommendations.

Case 2 – Fire pump bearing failure due to lack of lubrication

A newly commissioned fire water pump at a Middle East refinery repeatedly suffered high non drive end (NDE) bearing temperatures during periodic test runs and eventually caused a bearing failure. It was revealed that bearing failure was caused by a lack of lubrication since the failed bearing showed signs of lube oil starvation. However, the constant level oiler sight glass showed the oil level as full.

This begged the question: Why was the bearing starved of oil? The answer: The wrong orientation and installation of piping for the constant level oiler during the construction phase.

After correct installation of the constant level oiler piping orientation, the problem was resolved. As this fire water pump was emergency duty equipment, it would have failed during a real-life scenario and could have burned down the whole plant.

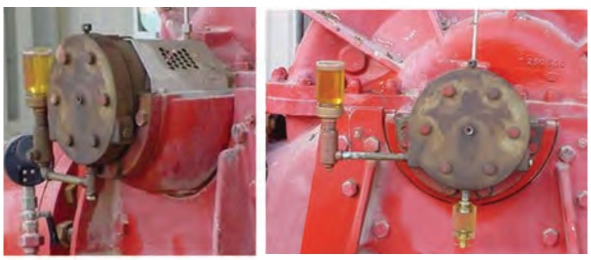


Figure 3: Constant level oiler orientation, before and after correction (Source: a Middle East refinery)

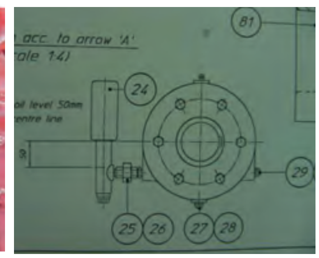


Figure 4: Correct orientation of constant level oiler (Source: vendor fire pump drawing)

Lessons learned:

Construction contractors should strictly follow vendor recommendations for equipment and piping installations.

Peer review of equipment and piping per vendor drawings should be part of construction audits to avoid these critical defects.

The need to review the piping of all other fire water pumps to identify possible installation errors was emphasized.

Case 3 – Low mean time between failures of mechanical seals

Since the commissioning of one Middle East refinery (nearly four years), mechanical seals of centrifugal pumps were observed to have an average mean time between failures (MTBF) of approximately six months. The reliability section conducted an investigation to identify and eliminate the causes of the fault to extend the life of the seals. A prelimanary review revealed that the majority of failures was associated with the failure of primary seals installed as per the American Petroleum Institute's API 682 Mechanical Seal Plan 23/52.

The site survey revealed the wrong installation of seal flushing piping and incorrect orientation of seal oil cooler as per API 682 Plan 23/52 on the 14 pumps on critical duty. In addition, the piping between the seal, cooler and barrier reservoir was observed to have many elbows, sharp bends, long piping and vapor lock opportunities. Thermal IR imaging of the seal system further confirmed poor performance of the seal oil coolers. The mechanical seal vendor recommended correction of the seal piping arrangement and cooler orientation to achieve efficient operation of the seals. The use of elbows, long piping and sloping down from the seal to the cooler had to be avoided to minimize pressure drop and possible vapor locking/hampering of proper flush flow.

These avoidable installation errors of the seal system probably contributed to the resulting overheating of the primary seal faces and caused premature failure of seals.

If these installation defects had been rectified during the early phase of the project, it would have avoided the high maintenance cost of seal replacements estimated to be one million dollars since plant commissioning. In addition, the MTBF would have been a few years instead of six months.

Lessons learned:

If a reliability program had been in place in the early project phase, it would have eliminated these avoidable defects and delivered higher uptime performance at a lower cost.

Always check the functionality of the mechanical seal system during precommissioning activities as per seal vendor recommendations.

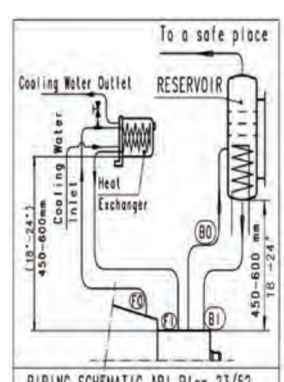


Figure 5: As per API 682 Plan 23/52, the seal oil cooler should have be 18 to 24 inches above the pump to generate proper thermo siphon flow of flush oil. The flush out line from the seal should be connected to the top connection of the cooler, whereas the flush in line should be connected to the bottom connection of the cooler. (Source: API Standard 682)

Figure 6: The wrong orientation of seal oil cooler installed below pump center line (Source: a Middle East refinery pump)

Figure 7: Elbows and long piping installed in seal flush circuit. The flush out line from the seal is connected to the bottom connection of the cooler, whereas the flush in line is connected to the top connection of the cooler, creating an incorrect installation. (Source: a Middle East refinery pump)

Case 4 – Live performance monitoring maximizes pump life and minimizes LCC

The key to achieving extended, trouble-free operating life of high energy (>500 kW) multistage centrifugal pumps is to operate them at best efficiency point (BEP). Operating away from BEP shortens pump life. Running a multistage pump (<3000 kW) at 30 percent BEP could reduce the pump life by up to 50 percent, as shown in Figure 8.

Fifteen high energy (>500 kW) critical pumps in an Exploration and Production (E&P) project in the Middle East as part of an engineering procurement construction (EPC) package were about to be installed in an online condition monitoring system based on bearing vibrations and temperatures. The reliability team decided to include pump live performance curve plots and motor current signature analysis into the online condition monitoring package at a minor cost difference.

The pumps' performance data from the factory acceptance test (FAT) was used to extract the BEP and the actual performance curves were plotted as the reference input for the software. See Figure 9 of the actual reference curve for a variable speed pump, along with the pump operating point (green zone being 'optimum,' amber zone being 'acceptable' and red zone 'avoid'). Monitoring pump performance during the operation phase and keeping it within the BEP optimum zone extends pump life and minimizes lifecycle cost (LCC).

Lessons learned:

Live performance monitoring for critical pumps should be part of an online condition monitoring program implemented in new capital projects for achieving extended long-term reliable performance and reduced energy cost savings achieved by operating in the BEP optimum zone.

	% maximum life if run at 50% BEP	% maximum life if run at 30% BEP	% maximum life if run at 20% BEP
Small pump (<30kW)	95%	90%	80%
Mid-size pump (<450kW)	90%	70%	60%
Multistage pump (<3000kW)	75%	50%	30%
Large multistage pumps (<18 500kW)	60%	25%	0

Figure 8: Influence on pump life of operating away from BEP (Source: Predictive Maintenance of Pumps Using Condition Monitoring by Raymond S. Beebe, Pub. Date: April 2004)

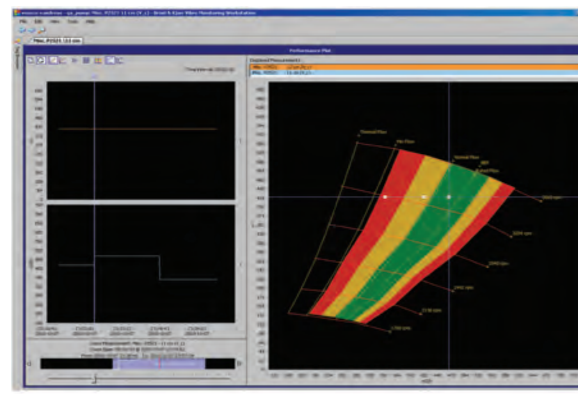


Figure 9: Screenshot of actual reference curve for a variable speed pump, along with the pump operating point (Source: Bruel & Kjaer Vibro Compass 6000 Performance Monitoring module)

Case 5 – Lubricant rationalization avoided cross-contamination and reduced cost

An upstream E&P project in the Middle East had a list of 582 machines with 624 lubrication points having an initial list of 22 different lubricants (oils and greases) recommended by different equipment OEMs. A rationalization study was conducted to consolidate the list of lubricants. Based on strict quality criteria, a single lubricant supplier was finally selected and awarded the contract to supply all the lubricants required for the project. All major types of lubricants were covered by the selected supplier, in addition to lower delivery lead time, cost efficiency, a provision of minimum stock quantity at the supplier's warehouse and training of staff on lubrication best practices. The outcome resulted in a reduction of the list to 17 lubricants with an initial lube purchase savings of $45,000.

Lessons learned:

Lubricant rationalization should be part of a reliability program for every new project to achieve long-term benefits, easier handling and reduced inventory cost, and avoid lubricant-related failures due to cross contaminations.

Conclusion

Implementing a reliability program in the early phases of a new capital project (engineering design, procurement, construction and commissioning) gives the greatest benefits. Reliability initiatives taken during the initial phases of the lifecycle of a project results in maximizing the intrinsic reliability of the assets, thereby delivering higher uptime performance, improved safety, and reduced operation and maintenance costs for the project's life. Best-of-class organizations presently realize the impact of decisions made during the early development phases of a capital project, thereby investing in reliability programs in early project phases and minimizing the value leakage to retain the maximum net present value (NPV) possible.

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References: DiStefano, Robert. *Bridging the Gap Between Construction and Operations for New Capital Assets*. Uptime magazine: June/July 2012 • Beebe, Raymond S. *Predictive Maintenance of Pumps Using Condition Monitoring*. Amsterdam: Elsevier Science, April 2004 • Deloitte, *Effective Operational Readiness of Large Mining Capital Projects – Avoiding value leakage in the transition from project execution into operations*. Article: 2012. • API Standard 682: Pump shaft sealing systems for centrifugal and rotary pumps • Bruel & Kjaer Vibro Compass 6000 performance monitoring module.

Work Prioritization: Emotion vs. Logic

IMC 2012! Conference Speaker

George Mahoney

A Supervisor's Typical Morning

Its 7 a.m. and Rich's head is already spinning. He hasn't even finished his first cup of coffee and already three different customers have screamed at him. While the customers are from three completely different business areas, they have two things in common:

They each have an "emergency" that needs to be taken care of right now.

They each refer to themselves as THE most important person on site.

As a front-line supervisor and former journeyman pipefitter, Rich has always had a great understanding of how to quickly troubleshoot problems and keep customers happy. Unfortunately, things have changed drastically over the past few years.

He used to have mechanics ready and waiting to address "emergencies," but cutbacks and retirements have cut his crew size in half. To make matters worse, every time he personally takes care of an emergency, his manager chews him out for breaking into his maintenance schedule.

With limited manpower, Rich doesn't have enough mechanics to address all three "emergencies." Even if he could, how would he ever get the rest of the work on his schedule executed?

If you were Rich, how would you handle this situation?

Would you stay the course and execute your scheduled jobs to keep your boss happy?

Columns

Rows

×	0	1	2	3	4	5	6	7	8	9	10
0	0	0	0	0	0	0	0	0	0	0	0
1	0	1	2	3	4	5	6	7	8	9	10
2	0	2	4	6	8	10	12	14	16	18	20
3	0	3	6	9	12	15	18	21	24	27	30
4	0	4	8	12	16	20	24	28	32	36	40
5	0	5	10	15	20	25	30	35	40	45	50
6	0	6	12	18	24	30	36	42	48	54	60
7	0	7	14	21	28	35	42	49	56	63	70
8	0	8	16	24	32	40	48	56	64	72	80
9	0	9	18	27	36	45	54	63	72	81	90
10	0	10	20	30	40	50	60	70	80	90	100

He used to have mechanics ready and waiting to address "emergencies," but cutbacks and retirements have cut his crew size in half.

Would you try to address one of the "emergencies" to keep one of your customers happy?

If you choose to address one of the "emergencies," how would you know which one to pick?

Logic versus Emotion

At Merek, a pharmaceutical company, we face similar situations. To help our maintenance personnel make these tough decisions, we are utilizing a tool known as the Ranking Index for Maintenance Expenditure (RIME), as shown in Figure 1. The RIME index was created as part of the implementation of SAP for plant maintenance and was developed by the Global Reliability Engineering Team in conjunction with the Global SAP Plant Maintenance Implementation Team. RIME helps replace emotion with logic. As we all know, most of our maintenance decisions are based on who is yelling the loudest and not what makes the best business sense.

Using RIME is very similar to using a multiplication table. You simply pick a column and a row, and where they meet is the answer. The rows correspond to the work request priority and the columns indicate the asset priority. Therefore, if you pick a work request priority and an asset priority, you can easily select the correct work order priority.

To make this more tangible, let's work through an example. Assume we are having a problem with a pump that is part of a manufacturing process. Because this pump is a process-oriented pump, we will need to use the column labeled "Process Equipment" within RIME (see Figure 2).

Assume the pump is still running, but is no longer providing the throughput required to optimally run the production line. As a result, we are still making product, but not at the desired rate to meet customer demand.

In this situation, we would use the row labeled "Reduced Production," as shown in Figure 3.

When you connect the row and column, you will see that they meet at work order priority #1 – complete within two days (see Figure 4).

Work Order Priority Codes

0 = Complete within 1 Day

1 = Complete within 2 Days

2 = Complete within 7 Days

3 = Complete within 30 Days

The Ranking Index for Maintenance Expenditures (RIME)

		Asset Priority								
		0	1	2	3	4	5	6	7	8
Work Request Code		Major Utilities	Safety / Compliance	Process Equipment	Support Equipment	Spare Process Equipment	Spare Support Equipment	Mat'l Handling Equipment	Production Building	Administrative Building
0010	"A" Safety / Loss of Production	0	0	0	0	0	0	0	0	0
0020	Major Compliance Issue	0	0	1	1	1	2	2	2	2
0030	Reduced Production	0	1	1	1	1	2	2	2	3
0040	All Others	3	3	3	3	3	3	3	3	3
		0 = Complete By End of Today; 1 = Complete By End of Tomorrow; 2 = Complete by End of Week; 3 = Complete Within One Month								

Figure 1

		Asset Priority								
		0	1	2	3	4	5	6	7	8
Work Request Code		Major Utilities	Safety / Compliance	Process Equipment	Support Equipment	Spare Process Equipment	Spare Support Equipment	Mat'l Handling Equipment	Production Building	Administrative Building
0010	"A" Safety / Loss of Production	0	0	0	0	0	0	0	0	0
0020	Major Compliance Issue	0	0	1	1	1	2	2	2	2
0030	Reduced Production	0	1	1	1	1	2	2	2	3
0040	All Others	3	3	3	3	3	3	3	3	3
		0 = Complete By End of Today; 1 = Complete By End of Tomorrow; 2 = Complete by End of Week; 3 = Complete Within One Month								

Figure 2

		Asset Priority								
		0	1	2	3	4	5	6	7	8
Work Request Code		Major Utilities	Safety / Compliance	Process Equipment	Support Equipment	Spare Process Equipment	Spare Support Equipment	Mat'l Handling Equipment	Production Building	Administrative Building
0010	"A" Safety / Loss of Production	0	0	0	0	0	0	0	0	0
0020	Major Compliance Issue	0	0	1	1	1	2	2	2	2
0030	Reduced Production	0	1	1	1	1	2	2	2	3
0040	All Others	3	3	3	3	3	3	3	3	3
		0 = Complete By End of Today; 1 = Complete By End of Tomorrow; 2 = Complete by End of Week; 3 = Complete Within One Month								

Figure3

		Asset Priority								
		0	1	2	3	4	5	6	7	8
Work Request Code		Major Utilities	Safety / Compliance	Process Equipment	Support Equipment	Spare Process Equipment	Spare Support Equipment	Mat'l Handling Equipment	Production Building	Administrative Building
0010	"A" Safety / Loss of Production	0	0	0	0	0	0	0	0	0
0020	Major Compliance Issue	0	0	1	1	1	2	2	2	2
0030	Reduced Production	0	1	1	1	1	2	2	2	3
0040	All Others	3	3	3	3	3	3	3	3	3
		0 = Complete By End of Today; 1 = Complete By End of Tomorrow; 2 = Complete by End of Week; 3 = Complete Within One Month								

Figure 4

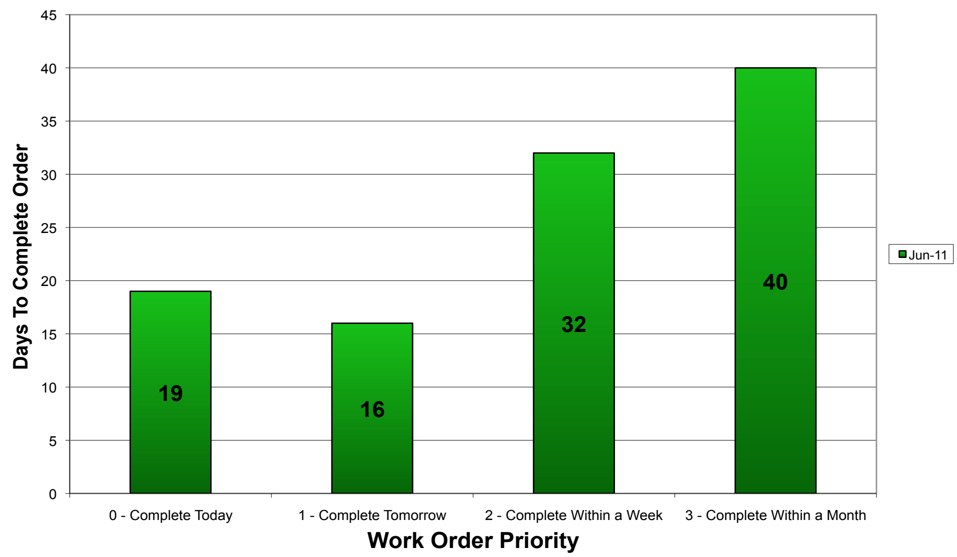

Figure 5: Median Time to Complete Orders: June 2011

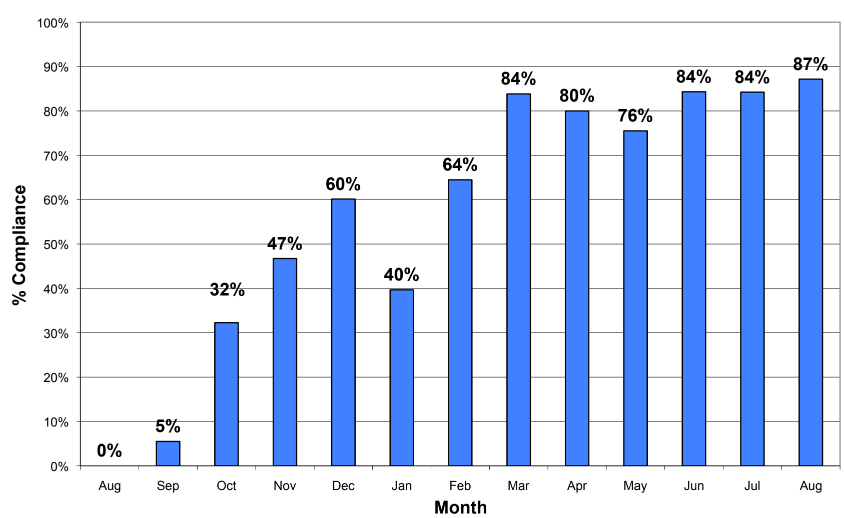

Figure 6: RIME Index Adherence By Month

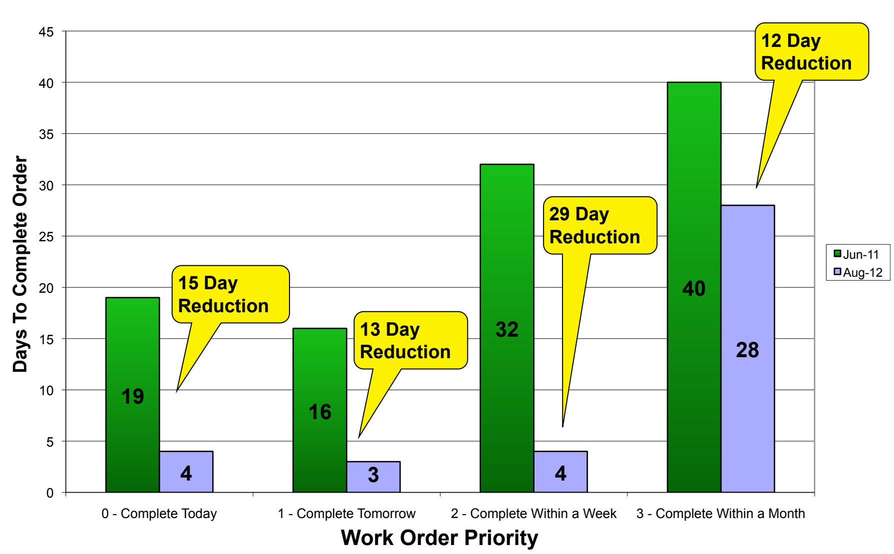

Figure 7: Median Time to Complete Orders: August 2012

Where Would We Be Without RIME

Before we started focusing on adherence to RIME, work orders were seldom completed by their designated due dates (see Figure 5).

When we dug deeper into the situation, we realized we were not following RIME 100 percent of the time. It was at this point that we decided to focus our efforts on proper work order prioritization. Each week, we would review work orders that were created and measure adherence to RIME. We did our best to provide praise to those who followed it and guidance to those who did not.

Within six months, we achieved our goal of 80 percent adherence, as indicated in Figure 6.

So What Does This Get Us?

While reviewing our progress to RIME adherence, one of our senior supervisors asked, "This is great, but what does it really get us?"

It is an excellent question.

Is all of this simply administrative work? Are we a better maintenance department simply because we code work orders properly?

To answer these questions, we had to go back and determine if we got any better at completing work orders by their designated due dates.

As can be seen in Figure 7, RIME adherence actually got us a great deal. By prioritizing work properly, we were able to achieve a two to three week improvement in response time for each work order priority.

Another nice benefit of focusing on work order prioritization is that our schedule compliance rose from 63 percent to 77 percent. As people began to put more thought into their work order coding, they were less likely to "break-in" to their existing schedule to get work done.

Wrap-Up

This issue definitely illustrates a paradigm in the maintenance industry. When you "feel" like you are providing the best customer service, you are actually doing quite the opposite. This became evident by our original data (Figure 5), where we acted on emotion and were unable to meet our deadlines.

When we replaced emotion with logic and RIME (Figure 7), we were able to truly meet customer demands and do so two to three weeks faster.

George Mahoney has worked in almost every facet of maintenance and engineering over the past 10 years. He served as a HVAC technician, a Design Engineer, a Maintenance Planner, a Maintenance Scheduler, a CMMS administrator and a Reliability Engineer. He currently holds the position of Reliability Excellence Lead for both North and South America at Merck.

Operator-Driven Reliability Best Practices Series:

Dave Staples

Coping with Innovation: No Place for Wimps!

IMC 2012! Conference Speaker

Think about how often a mobile phone or personal computer is upgraded, every two or three years? Do you think this is a ploy by the original equipment manufacturers (OEM) to make money? Maybe partly, but it is the only way to deliver the latest technology.

Every two to five years, there are major innovations for mobile devices in memory, processors, performance, displays, durability, size, connectivity and conveniences. So like it or not, innovations are coming and probably faster than you want.

Very few people like unexpected change. To minimize the distress of technology changes, plans should be put in place that anticipate the fast-moving technology window. In order for OEMs to deliver more hardware-dependent features, like Wi-Fi, enhanced cameras, global positioning systems (GPS), etc., they need to change the hardware platform of the mobile device.

The typical planned lifecycle of a mobile device is three to four years. As users of mobile devices, a technology lifecycle plan should be every four to five years. There also will be incremental software updates throughout the product's lifecycle, bringing new features, fixing "bugs" and improving performance. These updates are usually installed via software downloaded from an OEM website and are included in most maintenance or service agreements. These software updates are typically not as much a financial burden as making a platform change with the device. Costs associated with platform changes almost always require capital funding. And you know how much we all enjoy requesting capital funding!

The operator-driven reliability (ODR) sustainability team needs to plan for both types of technology changes, hardware and software innovation. The plan needs to incorporate the cost associated with the technology maintenance agreements and platform upgrades. Plans must also include the necessary human resources, in-house or sub-contracted, to roll out the technology, turn on and configure new features, and train the users. It is pragmatic to recommend utilizing resources experienced with the new technology to assist with these rollouts. Inexperience support deploying new technology can be inefficient and lead to rework. It all may sound fairly straightforward, but there can be hidden details to the plan. For example, training materials need to be updated. Infrastructure, such as wireless routers if going Wi-Fi for the first time, may need to be installed. If new features introduce new inspections, work process documentation may need to be updated.

Technology changes quickly. For companies staying in the forefront of ODR, this can be a good thing. Anticipating and planning for technology updates and upgrades can help make these changes seamless.

Dave

Dave Staples, Business Development Manager, SKF Reliability Systems, has over 20 years of industrial experience specializing in asset reliability technologies and asset management services. For the past six years, Dave has been focused on helping customers implement and sustain Operator Driven Reliability programs. www.skf.com

Work Execution Management — Pm preventive maintenance

Part 2

10 Steps to Pump Reliability

Tom Dabbs and Dan Pereira

Hopefully you read Part 1 of "Ten Steps to Pump Reliability" and have been anxiously awaiting to read Part 2 of the article. You may get the impression that implementing these steps will be costly and very difficult to achieve. The thing you need to bear in mind is: "You are already spending the money." The only question is: "Are you getting the result from your pumping systems that you are looking for?"

If you can create an environment that allows your entire team to become engaged in implementing these concepts, it will be the best investment you ever made. Deming said it best:

"Your system is perfectly designed to give you the results you are getting."

The decision is simple; if you want a different result you must change the system or continue living with the results you are getting.

We have collaborated to give you the benefit of our collective knowledge and experience with pumping systems and reliability techniques in hopes that it will help you improve the results you are getting and help make your business more profitable.

Now let's review steps 6-10 and finalize your journey to improve your pump reliability.

The top 10 steps you can take to achieve sustainable pump reliability are:

1. Proper Design and Equipment Selection
2. Proper Installation and Commissioning
3. Proper Flow Control
4. Proper Operation
5. Proper Maintenance
6. **Stock the Right Parts**
7. **Monitor Efficiency**
8. **Track Lifecycle History**
9. **Establish a Pump Management Program**
10. **Establish a Configuration Management Process**

Note: Steps 1 through 5 were discussed in the October/November 2012 issue of *Uptime* magazine.

6. Stock the Right Parts

One of the easiest and fastest ways to improve pump reliability is to use parts that meet the manufacturer's original specifications. In the pump industry, there are many parts replicators that sell replacement parts at reduced prices. Unfortunately, many times these parts do not meet specifications and do not have adequate quality procedures in place. Invariably, when we are asked to perform root cause analysis for our clients, these substandard parts are the culprit. If you choose to buy parts from replicators, make sure the supplier demonstrates the specifications and quality procedures that are used to produce the parts. But remember, the only time it makes sense to buy parts from replicators is when the original specified parts are no longer available.

To minimize the amount of parts stored in the storeroom, you should consider a power end exchange and repair contract with your supplier that will provide you with replacement power ends that are remanufactured to the original specifications and, in most cases, come with an as-new warranty. This approach minimizes the parts that are stocked in the storeroom and reduces failures caused by improper rebuild procedures. Mean time to repair (MTTR) can be reduced by replacing power ends, as opposed to a complete replacement or rebuild when a failure occurs. This approach can also minimize the duration of production interruptions.

If you choose to stock the parts necessary to perform your own in-house repairs, make sure you refer to the manufacturer's recommended repair parts list and stock the minimum amount required for each class of pump in your operation. Parts should be stored in a clean, dry environment and clearly marked with the appropriate stock or bin number for easy retrieval. Set appropriate min/max levels in your stores system to support the operation and set up an automatic replenishment process. If you store complete units or power ends, American Petroleum Institute (API) recommends that you rotate the shaft 1¼ turns on a monthly basis to prevent bearing flat spots and work hardened areas on the shaft.

7. Monitor Efficiency

Monitoring pump efficiency can be a very worthwhile endeavor in most manufacturing plants. Engineers and designers generally err on the side of oversizing pumping systems and do not always provide control systems that optimize energy consumption. Another factor is, as plants grow and are modified over time, pumping systems are not modified to perform the new requirements efficiently.

Two major factors that determine pump system efficiency are where the pump is running on the pump curve relative to best efficiency point (BEP) and what type of control system is used to control the pump output. Pumping against a partially closed valve is a terribly inefficient way to control pump output.

With these factors in mind, pumping system efficiency should be continuously monitored to ensure process demands are met at the lowest possible cost.

8. Track Lifecycle History

Data from computerized maintenance management systems (CMMS), when properly recorded and analyzed, will provide the data necessary to continuously improve performance and reduce the cost of your pumping systems. The key to this statement is "properly recorded and analyzed." From the analysis of this data, you can determine root causes, identify "bad actor" equipment and eliminate repetitive failures that, when resolved, offer tremendous potential for improving the company's bottom line.

If you use your CMMS religiously to plan and schedule all activities, record accurate data from the work performed and analyze data on a routine basis, then you are well on your way to tracking the lifecycle history of your equipment. The only thing remaining is taking action on the findings from the analysis you performed.

In our experience working with a wide range of industries, we have observed that many manufacturers struggle to maintain an accurate database of basic information on their equipment, let alone keeping track of the history of the equipment throughout its lifecycle. These issues have prompted our company, ITT, to develop Life Cycle Solutions, an asset management system that links specifications, purchasing data and performance date to a Web-based system using barcodes and smart phones so we can deploy an asset tracking system with very little action required. This system enables us to have our pumping system experts remotely analyze the lifecycle data to track mean time between failures (MTBF), identify bad actors and repeat failures, track replacement parts usage and provide other valuable improvement recommendations for our clients. It also provides real-time data directly to plant operating and maintenance teams, thus eliminating the need to leave the field to find information like pump curves and installation/operation/maintenance manuals, etc.

9. Establish a Pump Management Program

One way to capitalize on the principles outlined in this article is to establish a pump management program. Many of our clients have created teams consisting of management, technical, operations and maintenance resources that meet regularly and use these principles to improve existing pumping systems. These teams make sure the proper systems are purchased for new designs and expansions. When you consider the statistics outlined in the opening paragraph of this article, the opportunity to reduce spending and improve performance becomes apparent.

10. Establish a Configuration Management Process

If you have followed the recommendations in the first nine steps, you now have a reliable, efficient and cost-effective pumping system in your plant or facility. It is now time to establish a process to maintain the required information and adhere to it.

To maintain the integrity and accuracy of the data and information in our systems, there must be a process in place designed to continuously monitor the changes we make to our equipment and processes, plus update the information on a timely basis. Configuration management is that process and can be likened to a management of change process where equipment data, specifications, drawings, spare parts and other technical data is updated any time we make changes in the manufacturing process, modifications or upgrades to existing equipment, install new equipment, or discard obsolete equipment.

The configuration management process should be triggered by engineering and supported by management when changes are made to the design or operation of the plant. Included in the process is the provision that all affected plant personnel are given access to new information and training is provided to ensure safe and efficient operations and maintenance of the new equipment or processes.

If you have embraced all 10 steps in your pump management program, you have optimized the cost and efficiency of your pumping systems and know and understand the value for doing this. This may seem like a lot of effort to keep pumping systems running reliably, but when you compare it to the cost of continuous inefficiency and repeat failures, it makes it all worthwhile. Remember, everything you learn about keeping pumping systems running effectively and efficiently can be directly applied to all other assets, making this investment even more valuable.

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Dan Pereira has worked for ITT - Goulds Pumps for 25 years. He began his career as an applications engineer and moved on to sales engineer with a focus on the chemical/petrochemical, pulp and paper, engineer contractor and energy markets. Over the past 15 years, Dan has brought his expertise to the classroom, teaching general hydraulics, pump operation, pump maintenance and pump optimization for the petro chemical, pulp and paper, and energy industries.

Three Mile Island

Mission Critical Operational Reliability and Safety:

Learning from the Transformation of Commercial Nuclear Power

Mary Jo Rogers

Over the past 30 years, despite intense regulatory oversight and public skepticism faced by the nuclear industry following the accidents at Three Mile Island (TMI), Chernobyl, and more recently Fukushima, Japan, nuclear plants in the United States have undergone a complete transformation.

They are now the most productive, the most reliable and the safest they have ever been:

- U.S. nuclear power capacity factor has gone from 48 percent in 1971 to an average of 90 percent over the past decade.[1]
- Nuclear electricity production costs dropped to 2.14 cents per kilowatt-hour in 2010.[2]
- Total industrial safety accident rate was 0.09 (industrial accidents per 200,000 worker hours) in 2010.[3] In fact, it is now safer working at a nuclear power plant than in a school setting.[4]

How did the nuclear industry become safer, more reliable and more profitable while under such heavy scrutiny and regulation? And what can other industries learn from this transformation? The lessons learned through its practice and research program suggest that there are four key answers to these questions:

- Industry leadership,
- Self-regulation,
- Evolution of a safety culture,
- First-line supervisor.

Role of Industry Leadership

Forming INPO. In the aftermath of the TMI incident, utility CEOs recognized they were better positioned to address regulatory and plant performance challenges together than they were individually.[5] To that end, they formed the Institute of Nuclear Power Operations (INPO), which was incorporated in 1979 even before the President's commission released its final report on the TMI accident at the end of that year.[6] The World Association of Nuclear Operators (WANO) was formed after the 1986 Chernobyl disaster.

Through INPO, U.S. industry leaders took it upon themselves to address the commission's recommendations and figure out how self-regulation could work. Crucial to the success of INPO was the cooperation of senior leadership.

Cooperation and Information Sharing. Particularly through its plant evaluation and training programs, INPO played a key role in improving reliability and safety. The industry's cooperative approach to sharing information, best practices and even resources was a powerful factor in sustained performance improvements.

INPO's overarching standard is excellence in operational reliability and safety, and their primary means of holding the industry to this standard are their regularly conducted in- depth assessments of all U.S. nuclear power plants.

A good example of this cooperation occurred at River Bend Station, which is owned and operated by Entergy. In 2006, the plant had a number of reactivity management issues that forced them to take power reductions and shutdowns to deal with problems that were going to impact the reactor fuel. One of their reactor operators contacted Ed McVey, Exelon's manager of reactor engineering oversight, whom he had met at a meeting of the Reactivity Control Review Committee.

Although Exelon and Entergy are competitors, Ed spent a week with the River Bend operations department, providing feedback and suggestions that they implemented very successfully over the next year. Ed's decision to spend a week at River Bend was fully supported all the way up his management chain.[7]

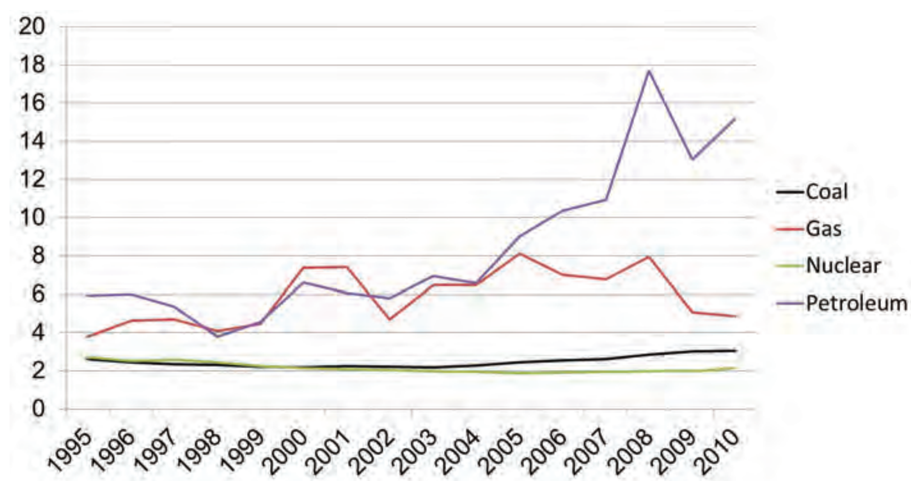
Self-regulation through INPO

INPO's overarching standard is excellence in operational reliability and safety, and their primary means of holding the industry to this standard are their regularly conducted in-depth assessments of all U.S. nuclear power plants.

U.S. Nuclear Industry Capacity Factor 1971-2011

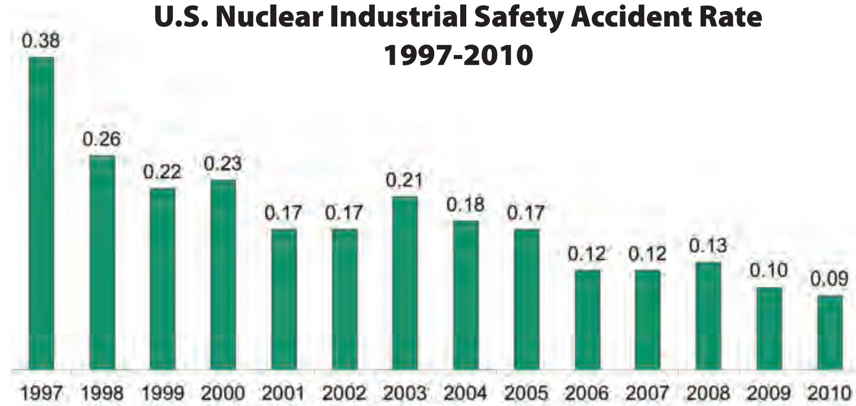
Source: Energy Information Administration, 2012.

U.S. Electricity Production Costs 1995-2010



U.S. electricity production costs, 1995–2010, in 2010 cents per kilowatt-hour.
Source: Nuclear Energy Institute, 2011.

U.S. Nuclear Industrial Safety Accident Rate 1997-2010



ISAR = Number of accidents resulting in lost work, restricted work, or fatalities per 200,000 worker hours.

Source: Nuclear News, 2011.

Each U.S. plant is evaluated once every two years against INPO's performance objectives and criteria. As part of this process, an assessment team, including INPO personnel and experienced professionals from other nuclear sites, spends two weeks observing how the site functions and reviewing data on its operating units. The assessment team's final report identifies strengths and areas for improvement, and plant leadership writes a response indicating what they will do to improve their problem areas.

Part of the impetus to improve and follow INPO's counsel has come from peer pressure. For example, every year INPO holds a conference developed exclusively for CEOs, Chief Nuclear Officers and Senior VPs of nuclear operating companies. This includes a closed session in which the CEOs are presented with a forced ranking of best to worst performers. Lower-performing plants and the utilities that own them are thus strongly challenged to improve.

This practice contributes to an important piece of the nuclear industry's transformation, which is the sense that industry leaders have of being "hostages of each other." In 1994, Joseph Rees's book by this title described how the industry changed after the formation of INPO due to leaders' belief that a disastrous incident at one plant would seriously impact the entire industry.[8]

Admiral Hyman G. Rickover

"You have to learn from the mistakes of others. You won't live long enough to make them all yourself."

This advice is often attributed to Admiral Hyman G. Rickover, known as the "Father of the Nuclear Navy."

Evolution of a Nuclear Safety Culture

A nuclear safety culture is defined by INPO as "an organization's values and behaviors—modeled by its leaders and internalized by its members—that serve to make nuclear safety the overriding priority."[9] Last fall, the Nuclear Regulatory Commission (NRC) officially defined safety culture as "the core values and behaviors resulting from a collective commitment by leaders and individuals to emphasize safety over competing goals to ensure protection of people and the environment."[10] INPO and the NRC both agree that safety culture includes having a safety-conscious work environment (SCWE), or an environment in which people feel free to raise safety concerns without fear of retribution.

Safety culture does not just mean avoiding accidents and injuries and creating a SCWE. It also includes process rigor: defining the correct, safe way of doing something and ensuring it is consistently done that way. In Strategic Talent Solutions' (STS) work with 35 different stations in the U.S. and England, it has become clear that building a stronger safety culture translates into getting better safety and production results in the long run. Field experience and the experience of senior leaders indicate that the following are useful ways to improve safety culture:

- Ensure that members of the leadership team have high standards around safety and reliability, that these are reflected in their behavior and that they are holding the organization to these standards.
- Identify, track and respond to precursors or small events before they have the opportunity to contribute to significant accidents.
- Enforce the rigorous use of human error prevention tools. Nuclear power has built these simple practices (including peer checks, three-way communication and procedure adherence) into many of its processes to help ensure safety and reliability.
- Regularly assess safety culture. Evaluate how safety norms and attitudes are actually demonstrated daily in behavior, decision-making and progress on safety results. This helps identify both the gaps in the safety culture and the areas in the organization that are most at risk.
- Build self-criticality and a learning orientation. Plants and companies that are willing to be open about performance are also in a better position to preempt problems because they identify them proactively. They are also more open to feedback from others in the interest of learning and improving.

Professionalism and Elevation of the First-Line Supervisor

The fourth key to sustaining improvements in the nuclear industry is the transformation of the first-line supervisor (FLS). Many years ago, the FLS was a foreman or step-up lineman; a "union guy" who was typically not necessarily aligned with senior management. The FLS functioned essentially as an experienced pair of hands working alongside the craftsmen and expediting work.

After TMI, there was a push for more extensive training, greater professionalism and a more important role for the FLS.[11] And although training subsequently improved, INPO analyses in 2004 led to the conclusion that supervisor weaknesses were still one of the most common causes linked to plant performance problems.[12] INPO emphasized that supervisors need to be in the field, but also need to have a greater oversight role, confront worker behaviors and be more aligned with site leadership.

In an STS research study on what makes first-line supervisors most effective, the authors found that supervisors who felt more like members of the management team were more effective at their jobs. And the most powerful ways to get supervisors to show that alignment were to: (1) treat them as core members of the management team, (2) give them enough time with their own managers and (3) tell them the reasons behind major decisions.[13]

Shift change. Over the next several years, the transition of the FLS to the management team will become increasingly critical for nuclear, as well as other industries. As an aging workforce of experienced supervisors and workers near retirement, a new generation of supervisors must step in to replace them. What we have seen work in this situation is pairing the experienced workers with the new talent in a mentoring capacity that mimics the apprenticeship model. In this way, they are more apt to get engaged because they have a junior counterpart looking up to them. They also may be more likely to feel needed in a way that isn't as physically demanding, but instead taps into their wisdom and potential desire to leave a legacy.

Summary

The nuclear power industry has changed dramatically since TMI and Chernobyl, and both reliability and safety have improved significantly in a highly regulated environment. The four ways in which other industries can learn from this transformation are:

- Taking leadership of change—and thereby taking control of your future.
- Self-regulation—use lessons learned from the formation of INPO, adapting to other industries.
- Building a safety culture that gets results in reliability.
- Transforming the first-line supervisor through better engagement and alignment with senior management.

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Reliability Engineering for Maintenance — Rcm vs. Fmea — reliability centered maintenance — failure mode effects analysis

RCM vs. FMEA

There Is a Distinct Difference!

Douglas J. Plucknette, Christopher Mears and Ramesh Gulati

IMC 2012! Conference Speaker

Introduction

There are many best practices (sometimes referred to by their buzzwords or acronyms) to choose from when it comes to maintenance and reliability (M&R), whether they be maintenance approaches/strategies (predictive maintenance, preventive maintenance, run-to-failure, etc.) or maintenance processes (planning and scheduling, total productive maintenance, maintenance logistics, etc.). Very few leaders in the M&R community would speak against any of these best practices. In fact, many of us in this community have an "all of the above" attitude when it comes to implementing M&R best practices; just choose which of these "tools" apply to your M&R and use those that make sense to you. A couple of the buzzwords or acronyms used over the years are reliability centered maintenance (RCM) and failure modes and effects analysis (FMEA). Some in the M&R community will continue with the approach of do both of them, while others will contend that one is better than the other. This article seeks to understand the differences and similarities between these two maintenance approaches/strategies and attempts to answer the question of whether RCM or FMEA.

RCM

Reliability Centered Maintenance

Douglas J. Plucknette

Reliability centered maintenance (RCM) is a reliability tool that is used to ensure the inherent designed reliability of a process or piece of equipment through the understanding and discovery of equipment functions, functional failures, failure modes and failure effects. In performing a RCM analysis, the RCM team uses a structured decision process to develop mitigating tasks for each failure mode identified during the analysis.

Like failure modes and effects analysis (FMEA), RCM can be performed in the design phase of a project. It is most commonly performed on existing equipment to develop a complete maintenance strategy in the hope of improving and sustaining the reliability of the asset.

While at first glance the two tools may look similar, there are some very distinct differences that will result in your effort coming up short should you use one in place of the other.

In addressing equipment functions, it is a requirement of RCM to address not only the function of the asset, but the performance standards we must maintain as well. FMEA functions are most often written at a higher level and do not address performance standards.

RCM failure modes are written at a more detailed level, addressing the part, problem and specific cause of failure (fuel pump motor bearing > seized > due to lack of lubrication). The detail of RCM failure modes is necessary to discover the correct mitigating task. FMEA failure modes are written at a much higher level (fuel pump motor will not run) and are written at this level because the FMEA process was designed to asses risk in the design phase.

RCM uses a structured decision process to determine a task to eliminate, detect, reduce the frequency of occurrence, or reduce the consequence of each specific failure mode. In doing so, the output of the RCM analysis becomes a complete maintenance strategy that is designed to ensure and sustain the inherent designed reliability of the asset. FMEA was not designed for developing maintenance tasks; it instead looks to mitigate risk of a failure mode through a recommended action that would occur in the design phase of the asset.

A good RCM process also addresses what should be done if there is not an applicable or effective maintenance task or redesign to address each failure mode. Here we look to reduce failure consequences' mean time to restore (MTTR) by identifying and implementing consequence reduction tasks (detailed job plans and spare parts assessment). This is not addressed as part of FMEA.

RCM was designed to discover and assess all types of failure modes, including failure modes that consider the operating context and environment, as well as process-based failure modes. As a result, it is important to understand that the best RCM facilitators are certified in a given methodology. This certification ensures the facilitator has both knowledge and experience in the RCM process and has the same level of understanding and experience in maintenance techniques and methods (predictive and preventive). FMEA, on the other hand, is an engineering tool designed to reduce risk before we install the asset.

The Challenges of RCM

Reliability centered maintenance (RCM) has been in use for many years, but is used more frequently as a structured, programmatic approach to improving an organization's maintenance program from a reliability perspective. The challenge is whether this structured, programmatic approach is a supporter or detractor to full implementation of the RCM approach.

In recent years, RCM has become a buzzword. Everybody wants to jump on the bandwagon and they want to do RCM. Many management executives, who have heard the name RCM, think RCM is a panacea for all their maintenance problems. They believe if they do RCM, it will resolve all their problems and their equipment will automatically become more reliable. In fact, several studies have indicated that the majority of RCM programs fail, either in the lack of implementation or in not achieving the expected benefits. It's not that RCM is bad; it's how it gets implemented, including the necessary buy-in from not only management but, even more importantly, the workforce.

Many organizations tried to implement RCM in the 80s and 90s and never truly succeeded. Many found that the perception about RCM was one of the biggest challenges. RCM was perceived and inappropriately portrayed to be a cure all for maintenance ills. Some of the RCM subject matter experts (SMEs) insisted on doing a full FMEA, looking for all failure modes (down to a single non-critical screw), which obviously takes quite a bit of time and resources. In some cases, a RCM analysis is not a good fit since it may be obvious what the maintenance strategy should be (just run-to-failure).

Another challenge of RCM is the perception that it's just another program. With all the various programs over the years -- total quality management (TQM), quality circles, Six Sigma, lean and many others -- many organizations did not grasp that RCM is a living process. Instead, they thought it was just another program-of-the-month. Therefore, they gave it lip service while they did it, halfway implemented the changes, and reverted back to their old ways of doing things once the RCM consultant left or the higher-level manager moved on to bigger and brighter things. Since many organiza-

In some cases, a RCM analysis is not a good fit since it may be obvious what the maintenance strategy should be (just run-to-failure).

tions touted RCM as a program and ran it like one, complete with a program/project manager, RCM went the way of many programs (out the door).

Other organizations have taken a different approach. After a few failures and several successes in implementing RCM, they learned that you can't enforce RCM in its purest sense or classical form as recommended by some consultants. What we are after is to keep equipment running – maintaining its functions at an optimal cost. Instead, they perform streamlined RCM or PM optimization efforts to improve the maintenance program. Sometimes, they perform FMEAs on groups of different types of equipment to get the most bang for the buck. And still others don't call it RCM (due to the bad taste in some people's mouths) and focus on the FMEA portion of the RCM process as a major tool in changing their maintenance program for the better. Doing these things typically cost less and show more benefits for organizations.

The Benefits of FMEA

Failure modes and effects analyses have been in use for many years in the M&R community because of their effectiveness and exhaustive application across many industries, as well as phases of the product, asset and facility lifecycles.

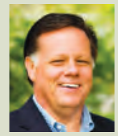
The basic process involves a number of major steps to complete a value-added FMEA, regardless of the type or purpose of that FMEA. In addition, there may be multiple minor steps within each of these major steps. Once a FMEA team has been established, the first step is to scope the FMEA effort, which provides a greater likelihood of successfully completing it. Next, the team defines the interfaces of the focused FMEA effort so the effects can be identified. Then the major components of the FMEA focus are defined (and broken down further as needed), along with each of their failure modes, root causes, failure indicators, failure criticalities, failure probabilities and effects using both team member experiences with the FMEA focus area as well as any available failure history. Some of the more traditional FMEA efforts stop here. However, we have seen the more effective FMEA efforts take this analysis and add to it the mitigation tasks and frequencies for each key characteristic candidates and identify the selected mitigation tasks to implement, ensuring that the selected mitigation tasks actually provide value by either detecting failure at the start of its failure mode or preventing a failure from occurring in the first place. The key to success of this FMEA process is in its application – only applying the individual step, as well as the detail of this step, as needed for the specific FMEA effort.

Probably the most common use of FMEA is for maintenance strategy development for a specific piece of equipment, product line, or facility. The preceding steps are used to identify the most likely failures, not necessarily all the failures. Of course, the number of failures within this analysis is dependent on the criticality of the FMEA focus. Once the appropriate mitigation tasks have been selected, formally documenting these tasks has proven to be a key factor to a successful implementation of the tasks. This formal document is the basis for an optimal predictive maintenance (PdM) and preventive maintenance (PM) plan. This optimal maintenance plan should identify any maintenance tasks currently being performed since this will impact the implementation plan. Finally, this formal document should also include any spares or specialized training needed for personnel (operations and maintenance) to execute the maintenance plan. The more formal this document is in your organization (for instance, an ISO-certified process document), the more likely the document will be followed once implemented. This document should become a living one, as should FMEA, in order for the overall maintenance program of that organization to be successful.

Over the last few years, organizations have started to incorporate FMEA as an integral part of capital investment and other design efforts. Although the use of FMEA in this part of the overall lifecycle approach to equipment and facilities has been occurring for only a short amount of time, the fruits of a FMEA look at equipment during the design phase are already reaping benefits and enabling long-term asset health, especially in ever-shrinking budget environments. Benefits of FMEA have been seen not only in reducing the potential for failures (reduced number of components and moving parts), but also in the introduction of PdM technology opportunities (including installation infrared windows in motor control cabinets equipment design) and right-sized optimization of the maintenance program (both PdM/PM and proactive run-to-failure decisions). Just as it is with maintenance strategy development, choosing the correct level of FMEA for a particular design is important in having a cost-effective design process with a maintenance flavor.

Conclusion

This article explores the differences and similarities between a RCM approach and a FMEA approach. In the end, it really is not a question of either/or. As you can see from this article, both approaches can be effective and can stand on their own without the other. The best approach really is an "all of the above" type approach. This allows you to select the most appropriate tools from each approach, as well as decide whether a formal program will benefit implementation of either approach or carries with it too much stigma of program failures of the past. As with all M&R best practices, education throughout all parts of your organization, implementation team, management team, and most importantly, those who will use it in the end, is your best strategy. Then let your newly-founded experts determine which approach best fits your organization.



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Outsmarting Varnish Avoids Costly Downtime

Measuring Varnish Potential in Lube Oil

Matt McMahon

Lubricating oil in gas turbines and hydraulic systems is unfortunately subject to the ravages of varnish. It is well-documented that varnish is an insoluble contaminant comprised of oil degradation by-products and sometimes depleted additive molecules. It is generally caused by some type of thermal (heat-related) stress placed on the oil. The debilitating effects of varnish include the loss of operating clearances within machinery and a loss of heat transfer due to thermal insulating. As more operators face the prospect of varnish in their lube oil systems, they are turning to oil analysis labs for answers.

Varnish: The Elusive Enigma

Whether tending to a gas turbine or a large hydraulic system, the mere mention of varnish can cause alarm and an immediate call to action.

"It's very important that a gas turbine and the hydraulic system work every time you start up or make changes. The cost of not starting up when required, or causing shutdowns, can cost in the thousands," says Raymond R. (Bob) Nichol, a Predictive Specialist for a major U.S. power company headquartered in Houston, Texas. "We check for varnish potential every six months and act on it if we start to see the varnish potential increase. The bottom line is by keeping the varnish potential under control, the equipment works when called on."

A number of explanations for the increasing occurrence of lube oil varnish have been postulated. Tighter filtration requirements, higher lube oil flow rates, higher operating temperatures and the switch to Group II base stocks in oil formulations have been offered as potential culprits in the decimation of lube oil systems. Varnish can often lead to unplanned outages and costly downtime, therefore, understanding and responding to varnish with remedial filtration is critical. Unfortunately, the ability to accurately measure varnish potential has remained elusive in routine testing.

"We work with power plants all over the country and their number one concern is varnish, specifically, making sure we are performing the necessary tests to alert them of a potential varnish problem," notes Michael Barrett, Vice President, Sales & Marketing, Insight Services. "We are continually looking for ways to improve the methodologies and technologies used in our laboratory to help customers solve problems."

Measuring Varnish Potential

A varnish potential analysis (VPA) is used to signal the development of lube oil varnish potential. This analysis combines multiple testing technologies to measure a lubricating oil's propensity to create varnish deposits.

This analysis combines the results of the following individual tests to provide a complete picture of a lube oil's varnishing potential.

1. **Membrane Patch Colorimetry (MPC):** This is an excellent tool in determining the varnish potential of an oil. This is a laboratory method of extracting insoluble contaminants from a used oil sample, followed by spectral analysis of the separated material. The process of making a patch isolates and agglomerates insoluble by-products associated with varnish. The color of the membrane patch provides a guideline as to the extent of varnish potential. With MPC, a direct correlation is made between the color and intensity of the insoluble contaminants and oil degradation. The test is designed to identify soft contaminants directly associated with oil degradation. This test is considered to be highly sensitive and reliable for detecting subtle changes in insoluble levels.

   As part of the MPC the *L*, *a*, *b* color values are also documented. The *L*, *a*, *b* values provide additional information on the particular varnish degradation mode and offer clues about the effectiveness of filtration targeting specific varnish modes. The *L value* is a black to white scale. The higher the *L value*, the higher the concentration of black particles in the oil. Black color can be due to soot particles, which can point to micro-dieseling, spark discharge, or hot spots. The *a value* is a red to green scale. The higher the *a value*, the greater the danger of sludge-building corrosive particles or diminished extreme pressure (EP) additives. Lastly, the *b value* is a yellow to blue scale. The higher the *b value*, the more susceptible the oil is to sticky deposits.

2. **Particle Count:** Particulate contamination is tested using two methods, optical and pore blockage. Optical particle count passes the oil through a beam of light. Anything in the oil that interrupts the beam is counted as a particle. This method will count soft (varnish) particles. Pore blockage particle count passes the oil through a calibrated mesh screen that captures only hard particulates. A significant difference in

the two results may be due to the presence of water, soft contaminants, or insoluble contaminants.

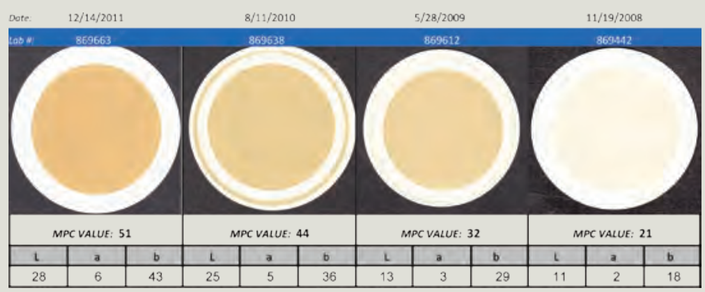
3. **Ultra Centrifuge Test:** A small amount of oil in a test tube is run for 30 minutes at 18,000 RPM in an ultra centrifuge. By subjecting the sample to significant G-forces, we are able to extract oil-degraded insoluble contaminants that are associated with varnish potential. Insoluble contaminants tend to have a higher density and will drop out during testing. The amount of the agglomerated material is compared to a rating scale to derive the UC value (1-8). This test is considered an excellent indicator of varnish potential.
4. **Remaining Useful Life Evaluation Routine (RULER®):** The RULER test uses linear sweep voltammetry to measure hindered phenolic and aromatic amine antioxidant content. The RULER quantitatively analyzes the relative concentrations of antioxidants in new and used oils in order to monitor the depletion rates of the antioxidant protection package in the oil. Hindered phenols and aromatic amines are primary antioxidants used in many industrial oils and turbine oil applications. By measuring the depletion and available reactivity of these antioxidant compounds while conducting other routine performance tests, the service life of used lubricants can be effectively monitored.
5. **Acid Number:** A significant increase in the acid number could be indicative of rising carboxylic acids associated with an oxidation condition. Monitoring the acid number alerts us to an increasing risk of oxidation. A rapidly rising acid number indicates antioxidant depletion.
6. **Karl Fischer Method:** This water determination test quantifies the amount of water in the lubricant. A reagent is titrated into a measured amount of sample and reacts with the OH molecules present in the sample. Results are reported as either % water or ppm (1% =10,000 ppm). Increased water concentrations indicate possible condensation, coolant leaks, or process leaks around the seals.
7. **IR Spectroscopy:** FTIR covers the monitoring of base stock degradation, oxidation and additive depletion in machine lubricants, hydraulic fluids and other fluid types. This test is based on trending of different parameters in various oils and fluids. For the turbine oil method, thermal event acid and acid oxidation are indicators of lubricant degradation. Ester, aromatic additive and base oil aromatic provide formulation information and should correlate with new oil data. Amine antioxidants and phenolic antioxidants are oxidation inhibitors with data expressed in indexing numbers.

Fighting Back Against Varnish

Varnish potential analysis should be considered a mandatory tool for any lube system that is prone to varnish. By controlling factors that influence or promote lubricant degradation, machine reliability and availability increases. By monitoring the contaminants responsible for varnish, reliability managers and maintenance planners can implement appropriate corrective actions before costly damage occurs and unnecessary downtime is experienced.

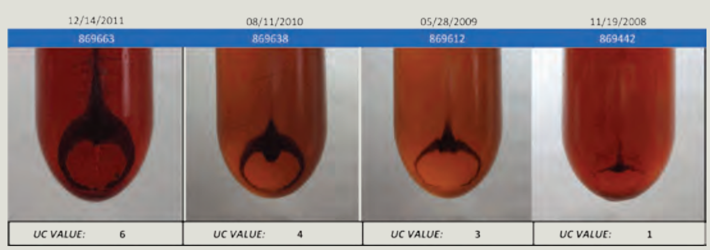
Results Summary

A varnishing potential analysis solution contains a vast array of information about lubricant condition. Understanding what the data means will enable you to take the corrective actions needed to avoid unexpected downtime.



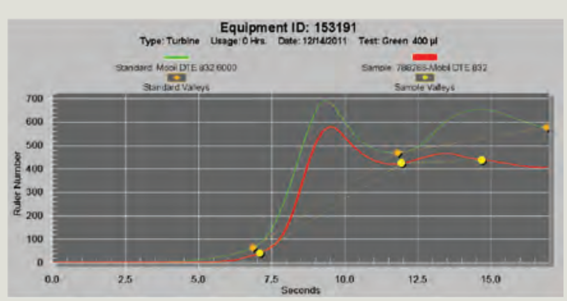
Membrane Patch Colorimetry Test

This MPC test depicts a color value of 51, which is above the critical limit of 50, indicating a high level of insoluble degradation products associated with varnish. The increasing b value also suggests the presence of degraded antioxidants.



Ultra Centrifuge Test

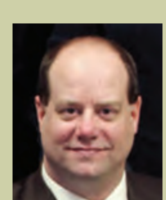
This example shows the sample has a UC value of 6, which is above the acceptable limit. These results correlate with the elevated MPC value (shown above) and indicate the presence of an elevated level of degradation byproducts associated with varnishing.



RULER Test

The RULER measures the remaining active antioxidants in the lubricant. This example shows that the level of amine antioxidants is 79%, and the level of phenolic antioxidants is 15%, of the new oil level. These results suggest the lubricant is at risk for varnish formation.

To download the Varnish Potential Report in its entirety: www.testoil.com/pdf/vpaw1.pdf.



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Understanding Why Structural Parts Crack

Ralph Buscarello

In the April/May 2012 issue of Uptime® magazine, an excellent article showed the different types of cracks that form in places due to what most engineering articles refer to as metal fatigue. The following article is written by a vibration specialist who claims there is no such thing as metal fatigue, but instead cracks form due to reversible stresses, reversing from tension to compression and back again, at the node of a resonant part.

As a review, see Figure 1 indicating the modal shapes of truly resonating parts. Note that the circles with the phase marks allow you to determine which direction the part is moving. The major part of the "curl" is called the antinode. The place of zero amplitude is called the node.

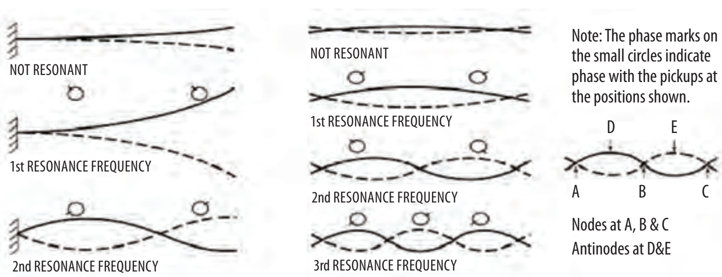


Figure 1: Resonance modal shapes showing antinodes and nodes

Note that the antinode portion with the largest amplitude in the "curl" shape is **not** where the metal cracks. Instead, see Figure 2 showing the resonance mode shape of a part when vibrating at its second resonance frequency (or a higher resonance frequency).

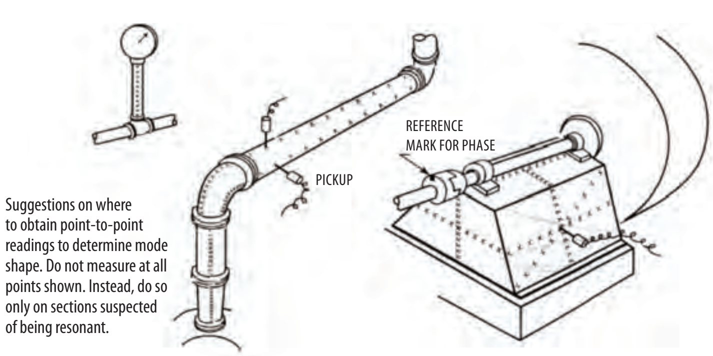


Figure 2: Typical locations for obtaining amplitudes for plotting resonance mode shapes

Note that the location of the smallest or almost zero amplitude is called the node. At one side of the node, the metal at the top surface is momentarily in tension. The bottom is in compression. At only a one-half vibration cycle later, the situation reverses. The surface that was in tension is now in compression. The surface in compression reverses to go into tension. Back and forth at the frequency of the vibration caused the resonance modal shape.

To get an idea of what is happening, hold in your hand a portion of the steel in an ordinary paper clip. Flex it back and forth with reversible stresses at the zero point. Within a minute or so, the steel will break at the node.

I have had many vibration consulting experiences where the problem was a part cracking about every two weeks or so. In every situation encountered, the resonating part modal shape was graphed showing curling at the antinodes and almost zero amplitudes at the nodes. Cracking, or "fatigue" as some would call it, always occurred at a node.

Never have I experienced cracks forming in situations where there was no resonance with its antinodes and nodes.

For example, the resonant sides of a gearbox would have at least one antinode. Update International instructors refer to this vibrating modal shape as curling. Assume that the sides of the gearbox are supporting the bearings that also support the gear's shaft. As the sides vibrate with the curling motion, the gear's shaft also moves in a motion that results in improper gear mesh. This increases the amplitude of the gear mesh vibration, causing the analyst to assume the gear was improperly machined or improperly assembled (yet, a slow roll of the same shaft would indicate proper mesh).

Nodes due to a resonance mode shape are also easily visualized on, for example, a cover plate, beam, length of shaft, etc. It is also known that fatigue cracks form at the nodes. However, not all analysts are familiar with how nodes and antinodes also form on a circular disc-shaped part, such as a spur gear.

Nodes and Antinodes on a Gear's Main Body

At the conclusion of a seminar, I was stopped by the operations manager of a large chemical company, who indicated one of the spur gears in a gearbox driven by a large steam turbine repeatedly fractured. Fracture and total machine shutdown occurred at an average of every 90 to 100 days. Each time, a new replacement gear would crack in about the same length of time (there were actually several turbines and gearboxes where this occurred).

I was reminded of an article written by Dr. Neville Rieger. The diagram in Figure 3 supplied by Dr. Rieger's article says it all. Note the equally spaced radial nodes. His diagrams recorded only the frequencies at which the

Figure 3: Nodes forming on a gear plate when increasing RPM and specific gear mesh frequencies cause resonances

nodes formed. The frequencies were very high and must have originated from the different gear mesh frequencies that resulted at different gear running speeds (it is assumed that at frequencies in between those indicated that the nodes and antinodes disappeared). The gear's RPM was gradually increased, thereby increasing much higher gear mesh frequencies. The four equally spaced nodes occurred at the lowest resonance frequency. The next, at higher frequency, showed a circular node. As the frequencies increased, more nodes and antinodes resulted. Dr. Rieger concluded that when a gear's rotational speed at the time of resonance remained constant, cracking formed at the nodes.

As with antinodes on a pipe or flat plate, such as the top or end of a steel base, antinodes and nodes also form on a round plate, such as a circular steel plate that supports fan blades or pump impeller blades. Instead of visualizing equally spaced nodes along the straight line of a pipe, for example, imagine the line with antinodes and nodes bent around into a circle. The spacing would be equal. The higher the resonance frequencies, the greater the number of nodes and antinodes. In the situation described by the operations manager, the turbine driver gear's rotational RPM created the specific gear mesh frequency to resonate the gear with several radial nodes. Finally, a complete fracture would occur at one of the nodes. Partially developed cracks at the other nodes revealed that they too were equally spaced.

In another gear that was very large, the gear would fracture several times a year, resulting in extremely high production as well as rebuilding costs. Calculations indicated that the gear's strength was several hundred percent greater than what was required. Yet fracturing started when the machine's operating speed was increased less than 10 percent. The gear's operating speed was under 500 RPM. However, there were over 100 gear teeth per gear. The very small RPM increase resulted in a gear mesh increase of well over 1000 cpm. The new gear mesh amplitude/frequency resonated in the angle between the rim and gear's main disc, resulting in a node that finally resulted in a crack. The crack at the node kept lengthening until the rim was weak enough to break off several inches. This shut down the whole paper machine. (See Figures 4-6 of the portion of the gear's outer rim with the gear teeth that broke off and stopped production.)

Figure 4: A sheet of 8 ½ x 11 inch paper to show gear's size

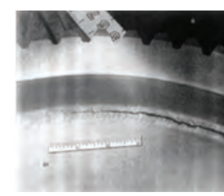


Figure 5: Crack forming at the resonant portion's node

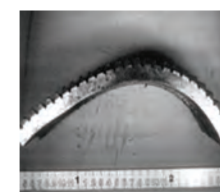


Figure 6: Portion of the gear's outer rim that would eventually break off, starting at the node

Symptoms of Nodes Developed by Resonances Due to Torsion:

Not to be overlooked are nodes formed from torsional resonance, which sometimes occurs in the rotor shaft itself. For myself, I found it only once in a Lamson blower rotor. The problem presented to me was a crack that developed just a couple of inches aft of the bearing next to the overhung flywheel with gear teeth around its periphery. The other cracks that developed were at the axial center of the rotor. The rotor's crack and complete severance at its axial center had its own unique shape. In other situations, the crack at the resonance rotor's node would break straight across the shaft, square with the rotor shafts diameter. However, the blower's torsional resonance would cause a node, whereby the torsional motion in one radial direction would be followed by a twisting motion in the opposite direction. Finally, the repeated torsional vibration would cause the rotor's torsional node to crack and result in a completely broken shaft.

As there were other Lamson blowers in the same section of the plant, I used a variable vibration speed vibrator to torsionally resonate another shaft. All resulting situations followed similar instances of vibration amplitudes becoming larger at the torsional antinodes and almost zero amplitudes at the torsional nodes. The main difference between the more common resonance breaks at the nodes and the less common torsional vibration amplitudes was the torsional cracks were not straight across the shaft (not square), but instead were breaking at a 45 degree angle.

The 45 degree angle break reminded me of the breaks I experienced as a 15-year-old student at Brooklyn Technical High School's Strength of Materials Laboratory. At that time, we saw all types of breaks called ultimate strength breaks. The usual break would be straight across, but the torsional ultimate strength breaks would be a 45 degree angle. That's how I put the two thoughts together and realized the break on the Lamson blower's axial center of the shaft was due to torsional resonance. It was then easily prevented by replacing the overhung flywheel with smaller and a different number of gear teeth. This produced a different torsional frequency that no longer resonated the rotor shaft's torsional resonance and therefore, did not result in a break at a torsional node.

From the information presented in this article, it could easily be assumed that the best solution to prevent cracks from forming at a resonating part node would be to search for the parts that are prone to resonate or are already resonating. To change the resonance frequency of those parts by changing their rigid bracing, adding weight, etc., would work, but may not be the easiest or lowest cost solution. In my experiences, I have found that a relatively large percentage of machinery rotor and structural parts, such as pipes, skids, gears, gearbox covers, etc., are resonant to vibration frequencies originating in other nearby machines. To eliminate the resonance in a resonating part, it is often easier to reduce the vibration amplitude that is originating at another nearby machine.

While these are only a few case histories, I have never been involved in a tough consulting problem where a crack formed was not due to a resonating part. Not a one.

In 1966, after 14 years in the field of machinery vibration and balancing, Mr. Ralph Buscarello founded Update International, Inc., as a vehicle for conveying his innovative principles of vibration analysis and control in simple, practical terms. As a pioneer and leading authority on vibration analysis, he has conducted seminars in over 50 countries worldwide.

IMC 2012! Conference Speakers

Uptime Magazine's Steve Thomas recently caught up with *Steve Beamer,* VP Reliability & Maintenance with BP-Upstream Global Operations in Houston.

Steve joined BP in October 2011and is responsible for reliability and maintenance on plant assets. This includes global work processes for Work Management, Defect Elimination and Production Efficiency Improvement.

Q&A

Q You are a keynote presenter at IMC-2012. Your topic is "Think Differently." Why do you think this is important, not just for reliability, but in areas such as personal health and finance?

A Albert Einstein said that insanity is "doing the same thing over and over again and expecting different results," yet I see people doing this in all aspects of their lives. The only way out of the trap is to step back and look at what's going on and try to make a correction. You may seek information and then experiment or you may go straight to action and take a trial and error approach. Most people want to have enough money to live a certain lifestyle, they want to be healthy, they want to have good relationships with others and they want to do well in their jobs. I left relationships out of the discussion because all I can offer there is if you recognize that your spouse is always right and you remember birthdays, anniversaries and special occasions, then you are well on your way to success.

Q How does thinking differently in areas such as finance and health tie in with thinking differently in the arena of plant reliability?

A I picked a couple of things that are fairly universal, that I know something about and that have a lot of parallels to draw on. As humans, the past few hundred years have taken us on a great journey of scientific discovery and industrialization, but we have lost a lot of knowledge that was transmitted through tradition, especially in Western society. We are at our infancy in learning about the human body, human behavior, how the brain works, etc. We are relearning and reproving the body of knowledge our ancestors built up over a long time and passed on through tradition as heuristics. We have tried to prove things through science in these areas and are only now realizing there are too many variables to isolate and most of what we learned in the last 150 years is flawed or wrong. These areas all tie together for me because there is a lot of conventional wisdom that is wrong and there are fairly simple processes you can follow and get tremendous results.

Q Thinking differently in a conventional industry setting isn't often a road to success, especially if you are not in a position of power. How can this approach be of benefit if you are not in power?

A When you think differently, you distance yourself from the crowd. It is quite easy to sound outspoken and come across as negative. Many people and organizations are very comfortable with their identity and you challenge that if you move too quickly or come across as smarter than others or above the fray. You need to establish your credibility by helping people. Present a single idea in a way like, "This doesn't seem to be working well. Could we try to do this one thing a little differently and see if it will work?" Change a few people first and build momentum. Always be conscious of the politics of the organization and make sure you are making your boss look good instead of making him or her look stupid. Be a likeable geek and not an outspoken anarchist. Show leadership by influencing others and changing behaviors.

Q Is conventional wisdom really helpful, or is it clouded with self interests portraying their solution as the best of the best?

A Conventional wisdom is usually based on common experiences of what has been successful in the past. If we think of Nasim Taleb's story of the turkey in his book, *The Black Swan: The Impact of the Highly Improbable,* the turkey gets fed every day for most of the year, is sheltered and gets to live a pretty good life, but just before Thanksgiving (in the United States), he gets his head cut off and shipped off to somebody's dinner. The conventional wisdom in this case is if you hang around here, life will be good. In reality, the turkey should be looking for a way out. Conventional wisdom is not always bad. I am suggesting that it should not be taken for granted and the context of the situation should be evaluated to make sure it still applies.

As an alternate thought: After World War II, the U.S. was one of a few industrialized nations in the world where the fighting did not occur on our soil. Our factories were new and we had a lot of trained workers. As the world struggled to rebuild itself, we supplied everybody. Our companies did well. People bought whatever we made. The stock prices of companies went up for a period of 20 plus years. Most of our parents grew up in this era. If you bought stocks of good companies and held on to them, they went up. Once all the competition returned to the world and globalization became more prevalent, this conventional wisdom of "buy and hold" is not true any more.

Q How do you separate the good from the not so good information represented as conventional wisdom?

A You think differently. You ask the questions: Where is this information coming from? Is somebody else benefiting from telling me this? What's the worse thing that could happen if I am wrong? (My costs go up, my health degrades, or I lose money in the market are often the answers.) Why does this work? Use your own knowledge and experience to test the ideas and seek others who have successfully done it. Why is it that Warren Buffett is the only guy who has become a billionaire by buying and holding companies? Maybe he is the statistical anomaly or maybe there's more to the story that we don't know about. Do you have everything he has to replicate his success?

Q There are a lot of people who can help you in the areas of health, finance and plant reliability. How do you determine who can really help when everyone says what they offer is what you need?

A First, I think that most people and companies have good intentions. They really believe what they are telling you and they really want to help. Second, you have to put the effort in yourself; nobody can do it for you. This is where many organizations come in. They hire the consultant and the consultant does everything and it works until the consultant leaves and then it falls apart. There is no substitute for discipline and accountability. Look for help from successful people and companies who fit your style or your company's culture. Look for people who want to teach you to fish. Look for companies that have successful engagements and then move on to new clients over and over again. If a company says, "XYZ has been helping us improve our maintenance for years, they're really great," this is a red flag for me.

***Q** You mention that thinking differently requires a culture change. What does that mean and how is it accomplished?*

A For you personally, thinking differently requires that you discard an old way of thinking or a habit and replace it with a new one. That's tough to do sometimes. For organizations, it is a huge disturbance that impacts morale by driving up uncertainty. It changes the power structure because different behaviors are rewarded that threaten those who have achieved the most through the old expected behaviors.

You change it by being brave, setting new standards, explaining why and appealing to people's emotions.

***Q** Which, in your opinion, is most important, the process to achieve the outcome or the outcome of the effort?*

A Outcomes can be achieved in the short term in many different ways, some good and some bad. Many managers take advantage of this and make themselves look good by damaging the company in the long term because they know they will be rewarded for the outcome, but they will be gone when the backlash occurs. The only way to make the outcome sustainable is to follow and stick to a process that manages the inputs. You can eat a strictly vegetarian diet with no white food (sugar, bread, potatoes, soft drinks, etc.) for a few weeks and have dramatic results on your cholesterol numbers when you go for your blood test, but that doesn't make you healthy for the long term. You can make one big trade and get lucky and make a lot of money, but that doesn't make you a financial success. You can stop doing maintenance and dramatically cut your costs without impacting your reliability that much for a couple of years, but don't expect your company to come out on top if you do it.

***Q** How do you get leadership to provide vision and direction in thinking differently about plant reliability when they are locked into a "break it – fix it" mode?*

A This is a tough one. In reality, all you need from leaders is for them to send the right messages to the organization by setting the right priorities, holding the course and demonstrating behavior that is consistent with the message. It's nice if you can get them to understand it and sometimes it's easier if you show them. But if you can just get them to change what they say and how they act, that's all you really need. For example, when something breaks, the operational leader usually asks, "When will we get that back on line?" That question translates to the organization as, "Get it back as quickly as you can!" If you can change that to, "I need to understand why that failed before we start it up again because we don't want this to happen to us again," the leader can now convey a sense of urgency to finding out why it failed and make an informed, business-driven decision about how to repair it and get it back on line.

***Q** Once you get people thinking differently, how do you sustain the process? This seems to be an easy task when things are going well, but not so easy during hard times.*

A To me, this is the role of leadership. The test of a true leader is staying the course in bad times. Usually, once you get through the initial installation and start seeing the benefits, people's habits change and it sustains itself. Nobody wants to go back to the old ways. Winston Ledet can give you a great example of this with the Lima, Ohio, refinery. The turnaround there happened over 10 years ago and despite two changes of ownership, the good practices and high performance remain embedded in the organization.

***Q** Conventional wisdom tells us planning and scheduling, PM, PdM and other similar processes will improve plant reliability, but these are just tasks. What is required to have these tasks lead to successful outcomes?*

A The Manufacturing Game™ references four stable domains of maintenance, which I paraphrase as:

• Regressive (death spiral) - slash costs and do as little repair as possible to continue to run.

• Reactive (most common) - react to defects and fix things as they break.

• Proactive (planned, scheduled, PM, PdM) - anticipate defects and fix them before they break so there are no surprises. This is the least stable domain because if too many things break in a short period of time, you fall back to reactive and must dig out again.

• "Don't Just Fix It - Improve It" (continuous improvement) - proactive, plus an effort to slow the rate of defects coming into the system by removing known defects.

In order to have these tasks lead to successful outcomes, I believe the organization has to see maintenance as a value-adding process and engage the whole organization in removing defects. It's a cross-functional contact sport. You must break down organizational silos and get people to work together and talk to each other to make this stick.

Book Review

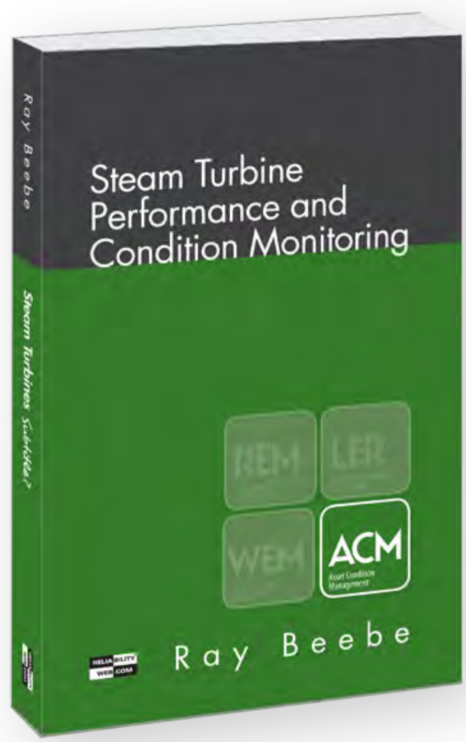
Steam Turbine Performance and Condition Monitoring

Written by Ray Beebe • Reviewed by Heinz P. Bloch

Over the past five decades, I have had ample reasons to consult many texts dealing with vibration monitoring and analysis. Truth be told, five or six of these cover the range from primers to tomes. I bought and kept these; they are now neatly stacked on one of my library shelves and are rarely opened.

Also, if someone had asked me a few years ago if I needed another book on a vibration topic, I would have answered in the negative. Part of my answer would have been attributable to fear of too much mathematics. Not that I lack appreciation for, or even lost, my somewhat dated---and perhaps even elementary---understanding of the subject of vibration analysis, but today's treatises are often too academic for my comfort. And so, I always believed that the world needed an infusion of practical know-how, a value-adding replacement strategy for lost talent, and solid training tools for generations of computer-savvy people who have trouble connecting with real-life machinery reliability (or unreliability) issues and events.

This book satisfies a true need; it answers questions. It represents an outstanding text and is written by an experienced and thoroughly practical engineer and university lecturer. Ray Beebe knows and elaborates on underlying theories when and as needed; he is truly connected to reality. As an exceptional writer-engineer, he conveys the practical aspects of vibration monitoring needed by industry to make up for the wisdom that took its leave whenever industrial plants suffered from early retirements and became handicapped by a regrettable attrition of expertise.



And the text has focus. Instead of delving into consultant-devised generalities on vibration, it concentrates on the total condition monitoring of steam turbines, a turbo-machine category that has been neglected because it seems complex. Mechanical drive steam turbines often operate at variable speeds; variable speeds do not make it any easier to interrogate or interpret complex vibration signals. Ray Beebe realized that an introduction to steam turbine performance is helpful and his book satisfies this need as well. I believe this text sufficiently covers all relevant vibration monitoring and analysis topics. It elaborates where elaboration is useful and adds value throughout.

Case histories will enlighten the reader on anything of importance, from leakage monitoring to the detection of mineral deposits on blades; from the determination of design-related root causes of vibration to diagnostic routines practiced by the author in his distinguished career.

This book is a text that begged to be written. It constitutes knowledge transfer of the highest order. I consider it a marvelous blend of straightforward practical experience and structured analytical approaches. I envy the readers who have access to it today and wish I would have held it in my hands a long time ago.

Heinz P. Bloch is a practicing consulting engineer with 50 years of applicable experience. He advises process plants worldwide on failure analysis, reliability improvement and maintenance cost avoidance topics. A frequent contributor to Uptime magazine, he has authored or co-authored 18 textbooks and over 500 papers.

Ray Beebe is Director of MCM Consultants where he provides training in the fields of predictive maintenance using machine condition monitoring. His career in engineering began in 1964 and he has worked in the industry for over 40 years, including teaching undergraduate and postgraduate students at Monash University. Ray is the author of three books including his just released title, "Steam Turbine" available at www.mro-zone.com.