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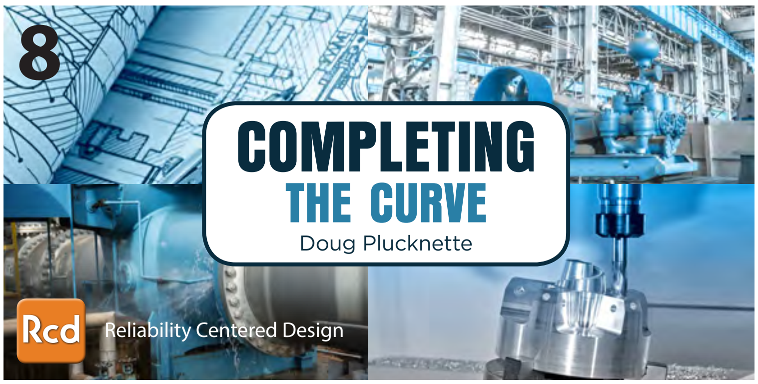

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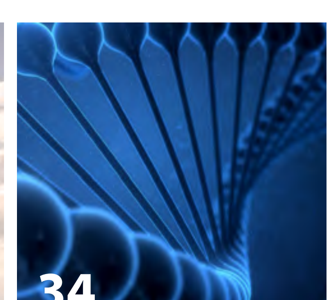

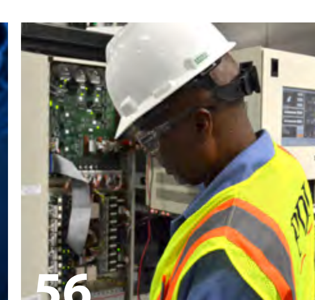

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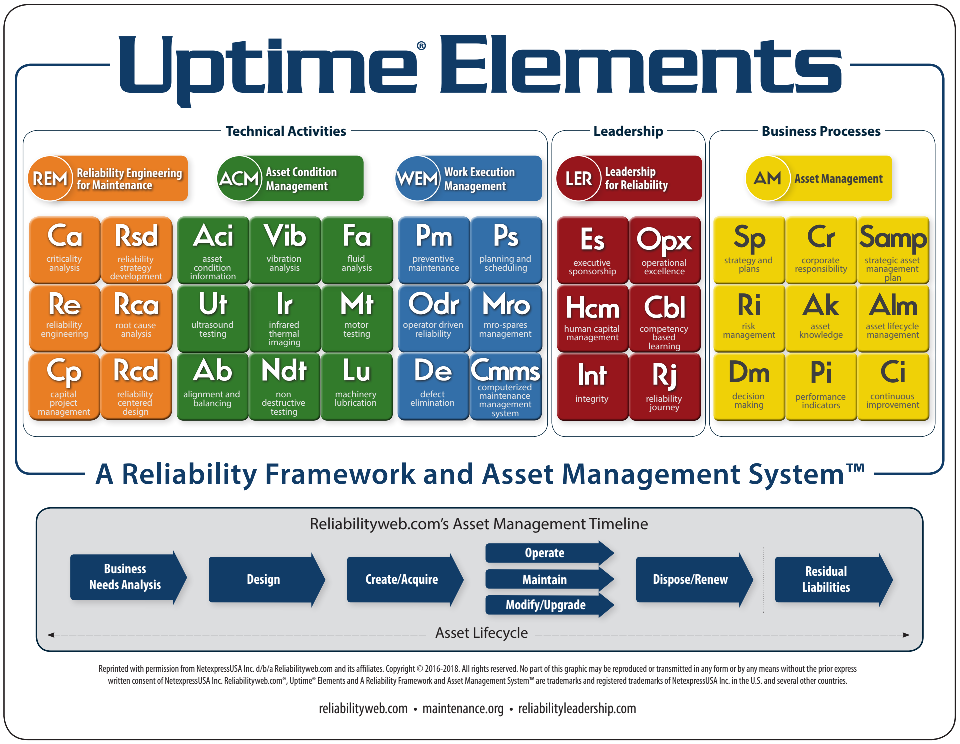

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DON'T GIVE UP ON ASSET MANAGEMENT

One of the most frustrating experiences of my life is also one of the most satisfying; however, to date, the frustration is winning.

As of this issue of *Uptime*® magazine, there are a grand total of three organizations in the United States that are ISO55001:2014 [Asset management – Management systems – Requirements] certified. Here is a link to an anemic list of organizations who have adopted and been certified ISO55001:2014 in the United States and around the world: http://uptime4.me/iso55000

In my opinion, there are dozens of reasons why the adoption is at a snail's pace. But in order to keep the peace, I will **not** expand on that topic – at least not yet!

I have represented the United States on the International Organization for Standardization (ISO) Technical Committee (TC251) in an effort to "Make American Asset Management Great Again" since the work began. When you combine public and private sector asset ownership, it turns out that the United States has 44 percent of the world's infrastructure and assets, so we stand to gain the most from managing them for whole lifecycle value, or better yet, for the value they can deliver to our society.

The satisfying part was the publication of ISO55001 in January 2014. A record-breaking three years was spent creating one of the first, new High Level Structure managing systems from ISO. The best and brightest from 32 countries worked collaboratively, albeit toward the lowest common denominator that would translate well to Russian, French and English.

To me, the frustrating part is the standard attempts to "engineer" a managing system for asset management that by its own admission is 100 percent dependent upon leadership and culture.

That is an important driver behind Uptime® Elements – A Reliability Framework and Asset Management System™, one of the few frameworks that combine managing assets (what you do to your assets) and asset management (what you do as an organization). This framework is built on a powerful leadership foundation designed to engage and empower cross-functional stakeholders, coordinating their activities across the organization.

Over the past year alone, we have been invited to embed Uptime Elements at a major aircraft manufacturer, a wood products company, a large mass transit organization, a Class I railroad, a global automobile manufacturer, several water utilities, an electrical transmission grid, a food products manufacturer, an international medical device manufacturer, a highly regulated life science organization, a federal nuclear lab and a huge integrated facilities management organization, among others. Each use the Reliability Framework and Asset Management System to unlock the potential that was already present in the culture and leadership of these great organizations. It works to advance their asset management journey in powerful ways. As a result, we are now working with organizations that represent over 1 million global employees.

The outcomes of that work are leading me to become less focused on engineering asset management (although that is important to get right). I am directing my efforts toward activating the good men and women of these organizations in a coordinated and aligned fashion to generate organizational objectives or the aim of the enterprise.

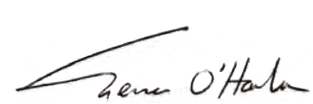
There is no asset management certification plaque on the wall but instead, a lot of smiles and many cases of a safer and more profitable organization to make up for it!

I am still driven to "Make American Asset Management Great Again," but my focus has shifted from certification to the work that creates an empowered culture and engaged leadership. I invite you to join me on that quest. Once you are on that path, it is a short journey to certification.

I hope you find the incredible work on the pages of *Uptime* magazine as useful in advancing that journey as I do. The team at Reliabilityweb.com teaches me about excellence in asset management by the example they set as they create magazines, books, conferences and 2,000+ Certified Reliability Leaders™ around the world.

I am grateful for the work they do and for the time and attention you give to read the work as a result.

Warm regards,



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IN THE NEWS

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RLI Face-to-Face Meeting

Reliability Leadership Institute's (RLI) Community of Practice (CoP) held its first 2018 member meeting at Central Arizona Project (CAP) in Phoenix, Arizona. This working group created a foundation for a performance management framework of cascading performance indicators (PIs) and key performance indicators (KPIs) related to Uptime Elements – A Reliability Framework and Asset Management System. Using the organizational objectives and asset management policy as starting points, performance measurement is aligned though "line-of-sight" from the top of the enterprise down to the asset!

The group also welcomed new members from Boeing and BNSF. The next RLI member meetings are at The RELIABILITY Conference in Las vegas followed by a co-hosted meeting by Siemens and Bentley Systems held at the Digital Innovation Center in Chicago, Illinois.

Congratulations to Tim Allen, Reliability Manager at CAP, who earned his Leadership for Reliability (LER) Uptime Elements Belt! Tim completing a significant LER project that was validated through the CAP financial department and executive management.

Uptime Awards 2018

There is still time to nominate your program for the 2018 Uptime Awards! The Uptime Awards recognize the best and most innovative reliability professionals in the world. Get the exposure and acknowledgment for your reliability and asset management program. The Uptime Awards Ceremony will be held at IMC-2018 in beautiful Bonita Springs, Florida.

Submission due by April 30th. Visit www.uptimeawards.com for more information.

Explore the Uptime Elements Black Belt Program

The Uptime Elements Black Belt Program is a results-oriented acknowledgment of significant and successful holistic reliability improvement projects delivered on a consistent basis. The goal of each successful Black Belt Program is to generate significant improvements in reliability and asset performance. Over 3 years, multiple Uptime Elements Black Belt Projects with a defect elimination focus will eliminate 54% of defects and 73% of defects over 6 years.

A minimum of one (1) from each of the Uptime Elements knowledge domains is required and once 5 Uptime Elements knowledge domain belts have been earned and confirmed, the Uptime Elements Black Belt will be awarded. Must be an active CRL in good-standing.

Contact: blackbelt@reliabilityweb.com

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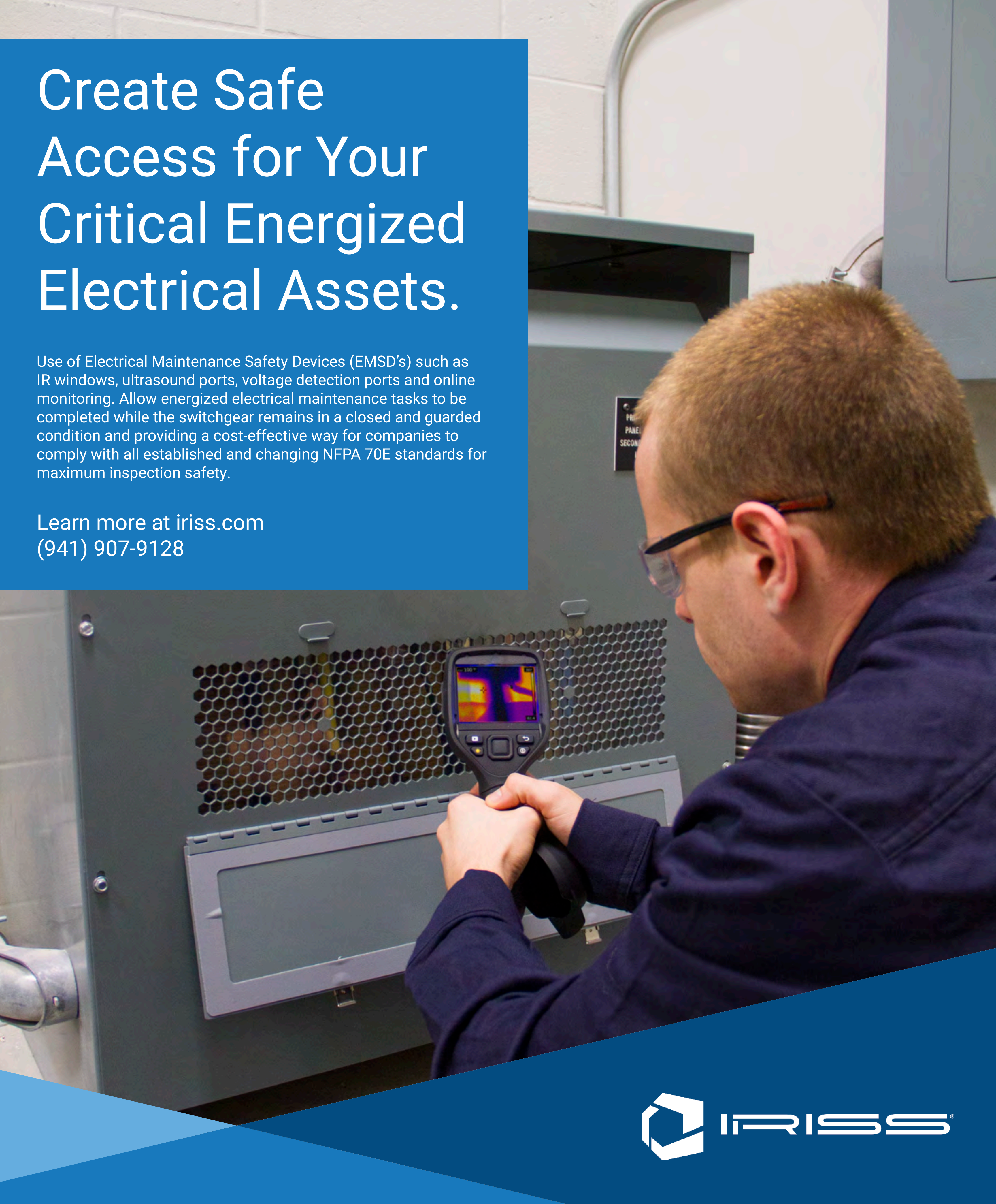
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COMPLETING THE CURVE

Doug Plucknette

Back in the June/July 2006 issue of *Uptime*, I authored an article entitled *Expanding the Curve* detailing why the traditional P-F curve was incomplete. While it was expected that the article might elicit both positive and negative comments, it came as a surprise how strong some of those opinions were.

The immediate comments were all positive. They came from a variety of people, most working in roles, such as maintenance supervisors, maintenance technicians and reliability engineers. Also commenting were three highly respected reliability consultants, one of whom asked why Point D was left out of the article. This consultant stated: "I am curious to know, in the article, after covering the importance of precision maintenance, you went on to discuss the importance of using a number of reliability tools and methods in the design phase. Shouldn't there be a Point D as well?"

Yes, in fact, the article and its illustrations should have denoted a D-I-P-F curve.

The negative comments came in a more indirect fashion. In public discussions on social media, several reliability-centered maintenance (RCM) practitioners commented on a somewhat regular basis: "When someone believes the P-F curve needs to be expanded, it's a clear indication that they truly don't understand the intent of the P-F curve." Attempting to explain the concept drew more personal criticism.

Over the next decade, different versions of the D-I-P-F curve presented by other people appeared in magazine articles, conference presentations and company conference rooms. Though the concepts behind these creations were being understood and taking hold, not a single illustration referenced the July 2006 *Uptime* article, which introduced this concept.

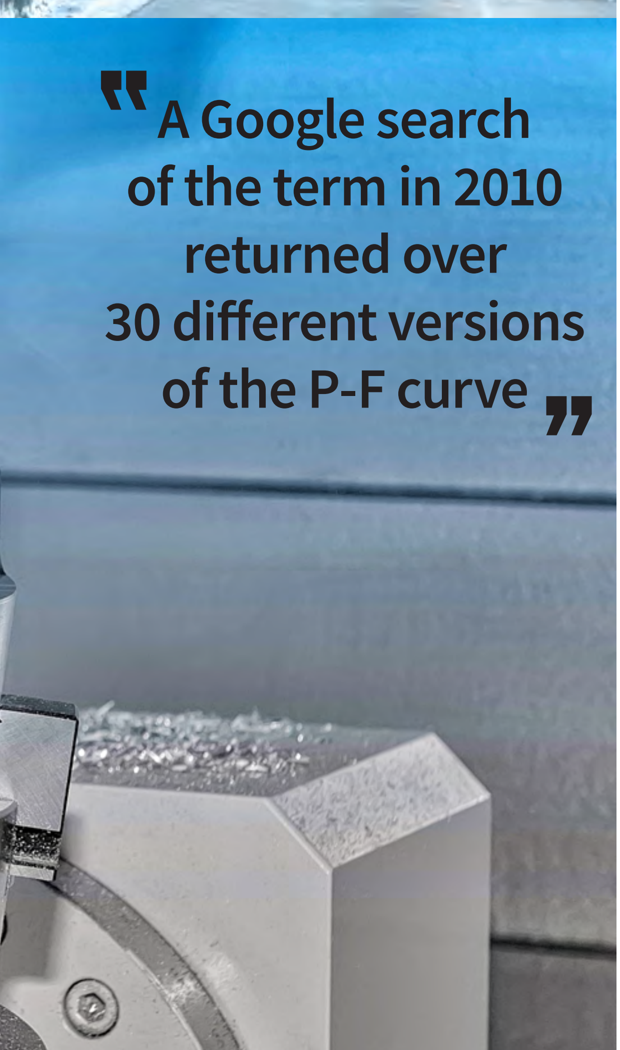
That all changed in 2017, when Terrence O'Hanlon, CEO of Reliabilityweb.com and Publisher of *Uptime* magazine, was working on creating some illustrations of various reliability concepts that included the complete P-F curve. However, he pointed out, "I've noticed there are versions of this floating around and not one of them credits you for developing this concept and that needs to be corrected." He added, "Not only that, I would like to copresent this concept with you as the keynote address for IMC-2017."

Needless to say, it was an honor to do so.

THE HISTORY OF THE P-F CURVE

The concept of the original P-F curve was first introduced by Stan Nowlan and Howard Heap as part of their 1978 document titled, *Reliability-Centered Maintenance*. Using an on-condition task of a visual crack as the measure of metal fatigue, they explained the diagram as Point A being new and the crack first appearing as Point B. At this point, the crack can be monitored until Point C, which they defined as potential failure, later to be known as Point P. Point D in their sketch is defined as functional failure, later to be known as Point F. This is the point at which the item should be repaired or replaced. Additionally, ΔT represents the interval of the on-condition inspection.

If you're a bit confused at this point, you should be. In the 1970s, on-condition maintenance in the industrial world had yet to be associated with the technologies known today.



"A Google search of the term in 2010 returned over 30 different versions of the P-F curve"

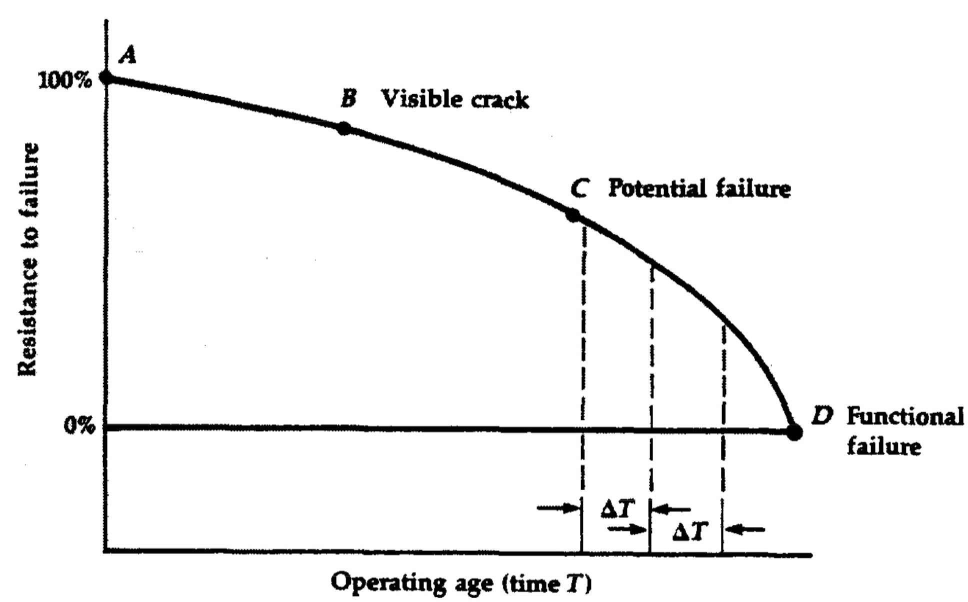


Figure 1: Nowlan's and Heap's original P-F curve

John Moubray, the creator of RCM2, cleared this confusion up in a big way with the release of his book, *RCM II Reliability-Centered Maintenance*. His section on the P-F curve did well to explain the association between the P-F curve and the ever-growing list of technologies available to help detect Point P for a given failure mode.

After reading Nowlan's and Heap's document and Moubray's book, you should have a pretty good understanding of the P-F curve and how you should be applying it to determine applicable and effective tasks to mitigate the failure modes you are experiencing with your equipment.

But that doesn't always happen. A Google search of the term in 2010 returned over 30 different versions of the P-F curve. While all may be well-meaning, most completely missed the mark, adding more confusion to something that should be straightforward.

UNDERSTANDING THE D-I-P-F CURVE

The idea to add to the P-F curve was driven by customers. One specific customer was struggling with a relatively new predictive maintenance (PdM) program. The organization had been applying vibration analysis to over 800 assets for three years. While it was somewhat pleased that Point P could be detected so it could plan, schedule and replace items before they failed, there was frustration from the fact that three months later, the asset would once again be in alarm.

The first RCM analysis revealed why this organization was struggling. While its PdM services company was outstanding at detecting Point P, the report offered little to no explanation as to the cause of the increased vibration, other than to say it was misalignment or looseness. Until the failure modes causing these alarms were identified and mitigated, they would continue to come back.

The RCM analysis identified over 140 failure modes, including:

- Misalignment;
- Soft foot;
- Pipe stress;
- Lack of lubrication;
- Cracked foundation;
- Improper belt tension;
- Improper design/application.

The failure modes on the list covered in the organization's first RCM had one thing in common – each one could be eliminated through either a simple redesign or good maintenance practices.

While a large percentage of reliability efforts are focused on detecting Point P, the truth is, if organizations simply did the right things, Point P would very seldom rear its ugly head!

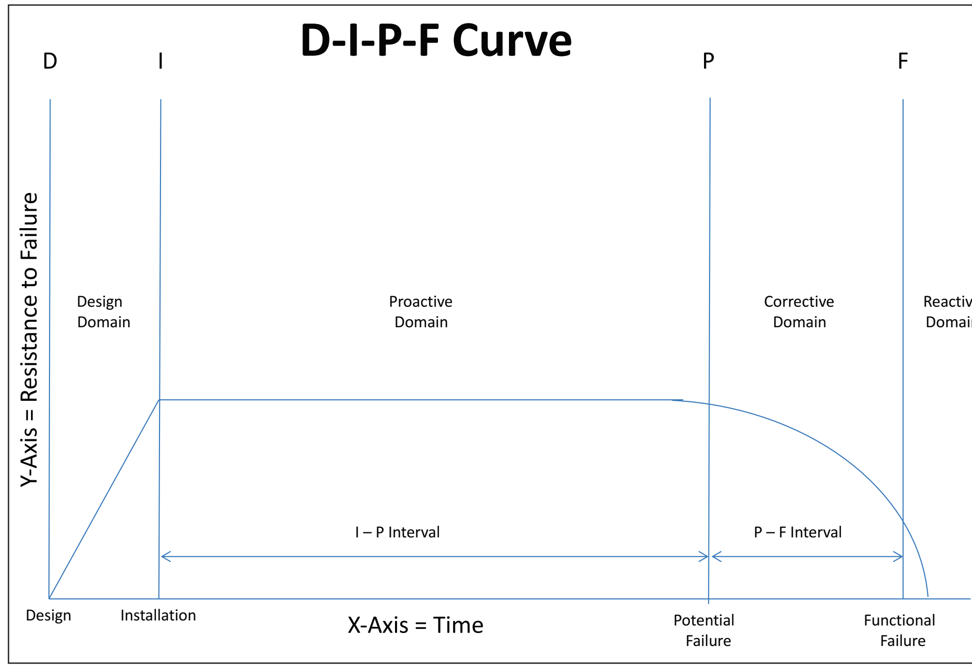


Figure 2: The first draft of the D-I-P-F curve, also known as the asset lifecycle curve, created for RCM Blitz® training materials in July 2006. *(D. Plucknette, Reliability Solutions Inc.)*

CHANGING DIRECTION STARTS WITH DESIGN

The first thing to always consider in terms of an asset's lifecycle is the inherent reliability you expect the system, asset, component, or item to deliver. Inherent reliability is the level of reliability the item will deliver when protected by a complete maintenance strategy that includes on-condition and preventive maintenance (PM) tasks. This being stated, all the maintenance in the world will not improve the reliability of a system, asset, or component whose inherent reliability is poor.

Now on to Point D and the design domain of the D-I-P-F curve. As part of Point D, you should take a close look at your capital improvement pro-

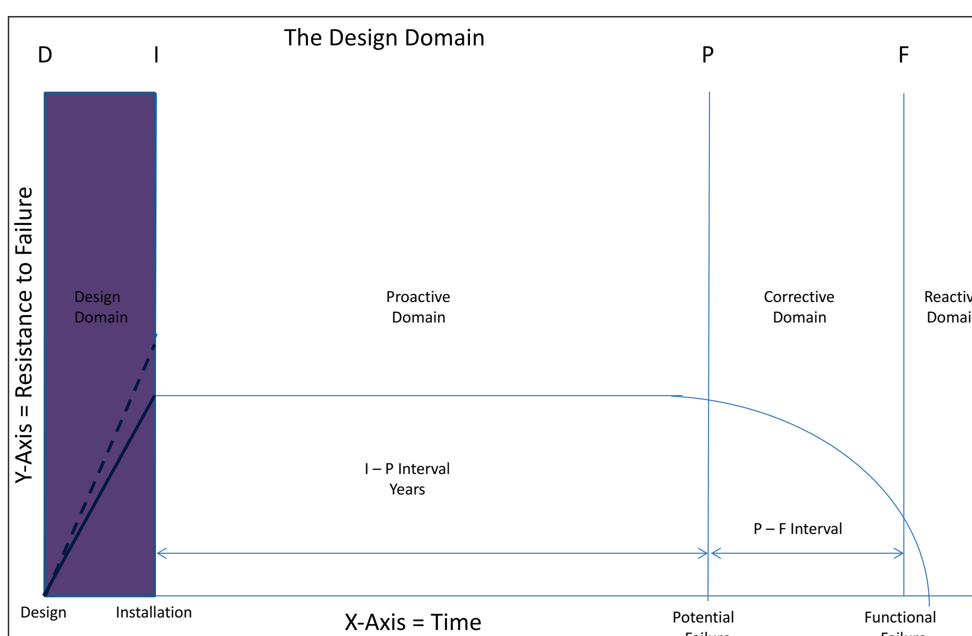


Figure 3: The design domain portion of the D-I-P-F curve where an asset's inherent reliability is determined; dotted line represents the understanding of designing for a level of reliability beyond performance expectations. *(D. Plucknette, Reliability Solutions Inc.)*

cess to ensure it uses a combination of tools that work together to achieve a strong or robust inherent reliability. This includes, but is not limited to:

- RCM Blitz®;
- Failure mode and effects analysis (FMEA);
- Reliability block diagrams;
- Select supplier agreements;
- Requirements documents;
- Design standards;
- Equipment hierarchy;
- Criticality analysis.

MOVING ON TO INSTALLATION

While it can't be stressed enough the importance of using reliability tools and techniques in the design phase of the D-I-P-F curve, Point I, for the installation domain, is where the rubber meets the road. The most reliable design can be ruined forever by poorly executed installation. Unfortunately, it is not uncommon with a brand-new installation to find mixing of metals on the same piping service, unsupported piping, loose or missing guarding, poorly wired panels and undersized foundations.

> "The most reliable design can be ruined forever by poorly executed installation"

At a time when company managers are dreaming about the benefits of the Industrial Internet of Things (IIoT), how is it they are still ruining perfectly good designs by totally messing up the installation?

Of 10 companies assessed in 2017:

- Eight had no formal installation standards when it came to their capital improvement program;
- Nine did not include mechanical, electrical, or instrument tradespeople as part of their capital improvement team;
- Therefore, nine did not have their maintenance tradespeople performing quality checks on the work performed by installation contractors;
- Zero knew if the installation contractor's tradespeople had completed formal skilled trades training.

They also had no idea, when asked, if the contractors could perform precision alignment,

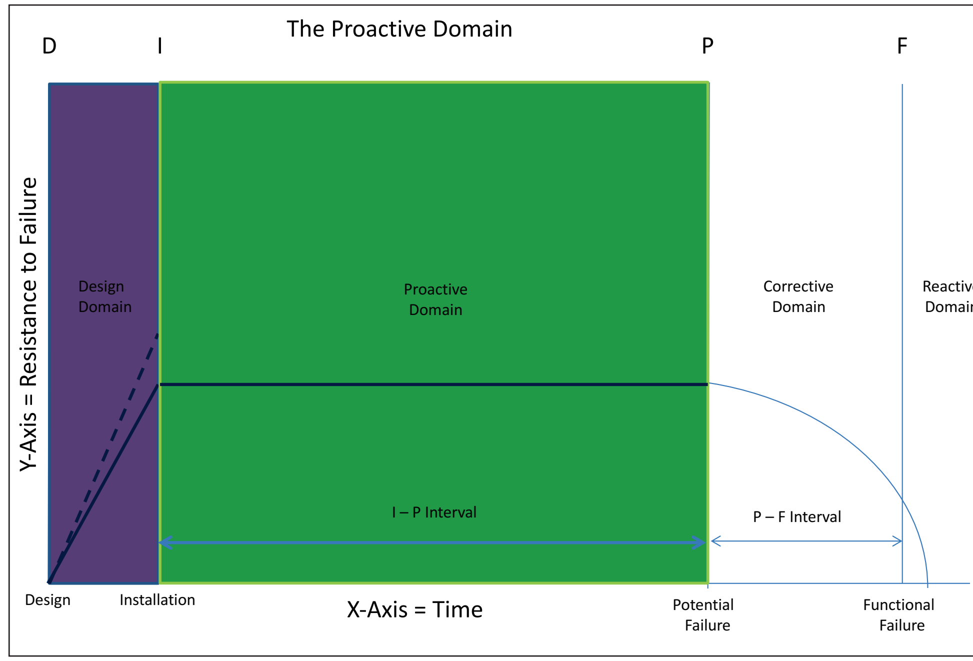


Figure 4: Proactive domain of D-I-P-F curve is where proactive equipment maintenance tasks are performed on a set schedule to ensure maximum I-P interval. *(D. Plucknette, Reliability Solutions Inc.)*

had the reference tables and ability to look up various bolt pattern and torque specifications for flange assembly, or had the proper certifications for installing explosion-proof wiring systems.

These dismal facts only will improve when your company recognizes these gaps and makes the decision to include asset reliability as part of its capital planning process. Companies also need to make sure their people are trained in the use of precision tools and the importance of following detailed installation standards. If you spent the time and used the methods and tools to ensure a good design, then make sure you cash in on those improvements with a great installation.

The additional cost of adding reliability tools and methods into your capital improvement process is one to three percent at best. It's a small price when compared to what you will gain in the very near future.

THE PROACTIVE DOMAIN

The proactive domain is where organizations recognize their return on investment for adding reliability tools, methods and resources to the capital improvement process. It is in this domain where you apply the proactive equipment maintenance plan developed through the application of tools, like RCM Blitz®, from the design phase of the D-I-P-F curve. This list of tasks includes continuous on-condition monitoring (IIoT), PdM inspections, PM inspections, operator care tasks, lubrication tasks and failure finding tasks.

The completion of these tasks at their scheduled intervals ensures the longest I-P interval possible. Failure to identify the tasks, complete the tasks, or poor installation practices drastically reduce the I-P interval.

Sadly, a large percentage of companies are experiencing drastically reduced I-P intervals because they fail to recognize the importance of installation standards when replacing failed components and they fail to complete their proactive tasks at their prescribed intervals.

While this might sound bad, it can get worse. Many companies try to fight this battle by living further right on the curve. The farther to the right you go, the more out of control and costly maintenance becomes.

DEFINING POINT P

Nowlan and Heap defined potential failure (Point-P) as: "An identifiable physical condition which indicates that a functional failure is imminent." This physical condition can be detected in many ways, including on-condition tasks (PdM), human senses and process verification/IIoT.

Some important things to understand about Point P:

- Point P is NOT where the failure occurred; it is where it is first detected. Bearings don't suddenly start to vibrate or get noisy and hot, something causes those physical conditions to occur. This cause is the failure mode.
- In many cases, Point P can be eliminated. If you can identify the failure mode that resulted in an identifiable physical condition, you can usually eliminate that failure mode with good installation and maintenance practices.
- Point P can and will move up and down the P-F curve, depending on the task being used to identify the presence of a physical condition. The best task for identifying Point P is

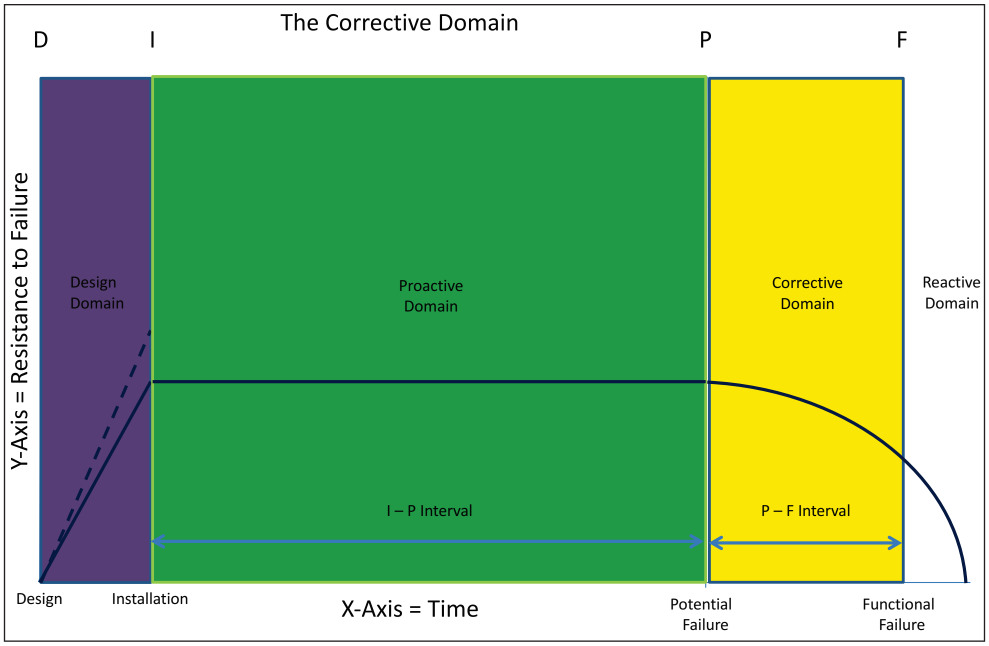


Figure 5: The corrective domain is where you plan, schedule and execute repair or replacement of items Point P has detected. *(D. Plucknette, Reliability Solutions Inc.)*

one that is both cost-effective and consistent in early detection of Point P.

- It is not uncommon to use multiple tasks and multiple physical conditions to ensure Point P is detected.
- Point P does NOT come with a known time limit. To be clear, once Point P is detected, the time it takes for the item to become functionally failed is unknown. What you do know is that once Point P has been detected, failure is imminent and will not be avoided without intervention.

THE CORRECTIVE DOMAIN

Also known as the P-F interval, the objective of the corrective domain is to plan and schedule repair or replacement of the item detected by Point P before a functional failure occurs.

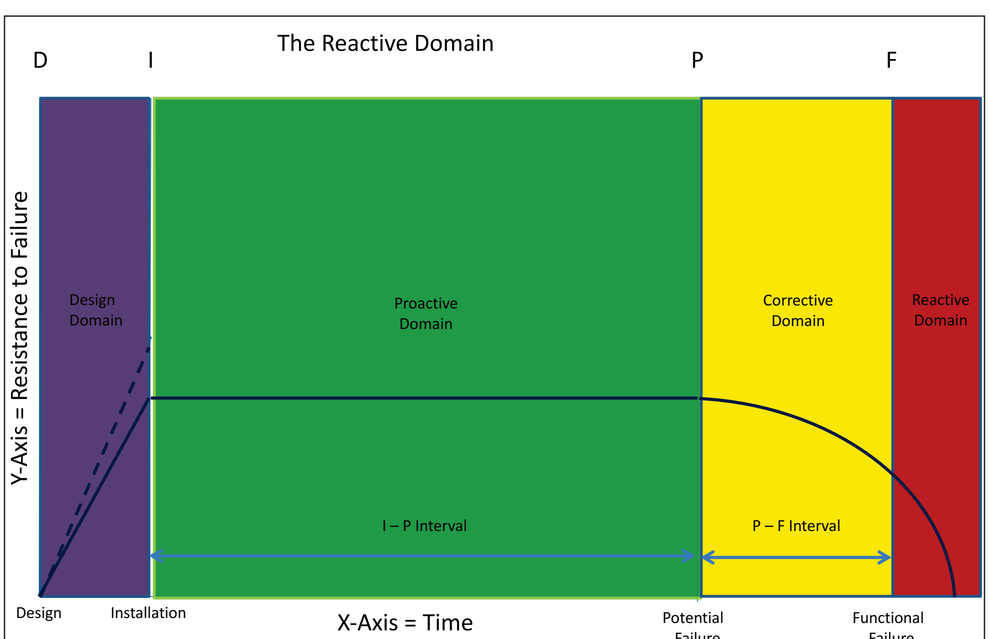


Figure 6: The reactive domain, by far the most expensive domain in which to perform maintenance because secondary equipment and component damage has already occurred, multiplying the cost of repair more than five times compared to completing it in corrective domain. *(D. Plucknette, Reliability Solutions Inc.)*

Important things to understand about the P-F interval:

- Every component and part at your plant fits the P-F curve. The difference from one component or part to the next is the time it takes to go from Point P to Point F. Depending on the component, part and failure mode, the P-F interval could be months or a fraction of a second.
- The P-F interval is critical in helping you make sound on-condition task decisions. Component/part and failure mode must have a useful P-F interval and be cost-effective for an on-condition task to be considered applicable and effective.
- The interval for an on-condition task should be one half of the P-F interval or less to ensure the identifiable physical condition is always detected.

While some companies accelerate the frequency of their on-condition tasks, once Point P has been detected, this practice often leads to destructive behaviors and does nothing more than increase the cost of failure. Once you have detected Point P, you should immediately plan and schedule the repair or replacement of the item as soon as possible. As pointed out earlier, once Point P has been detected, failure is always imminent. Additional testing only brings a false sense of security while, at the same time, casting doubt on the technologies used to detect Point P. If you want the technologies to have a sustained presence in your maintenance organization, you have to have the discipline to believe in them and replace the item as scheduled.

POINT F

Point F on the D-I-P-F curve designates the point at which the item becomes functionally failed. Nowlan and Heap defined functional failure as: "The failure of an item to perform its normal or characteristic actions within specified limits." The understanding of what functional failure means to your equipment is critical in the successful application of on-condition maintenance. Point F is where many people become confused with the P-F curve, as evidenced by several illustrated versions available on the Internet that show total failure or an explosion graphic as Point F, which could cause confusion between functional failure and catastrophic failure.

In simple terms, Point F or functional failure is the point at which your component is no longer able to function at a specified performance standard. As an example, if you expect a centrifugal pump to supply a liquid at 120 gallons per

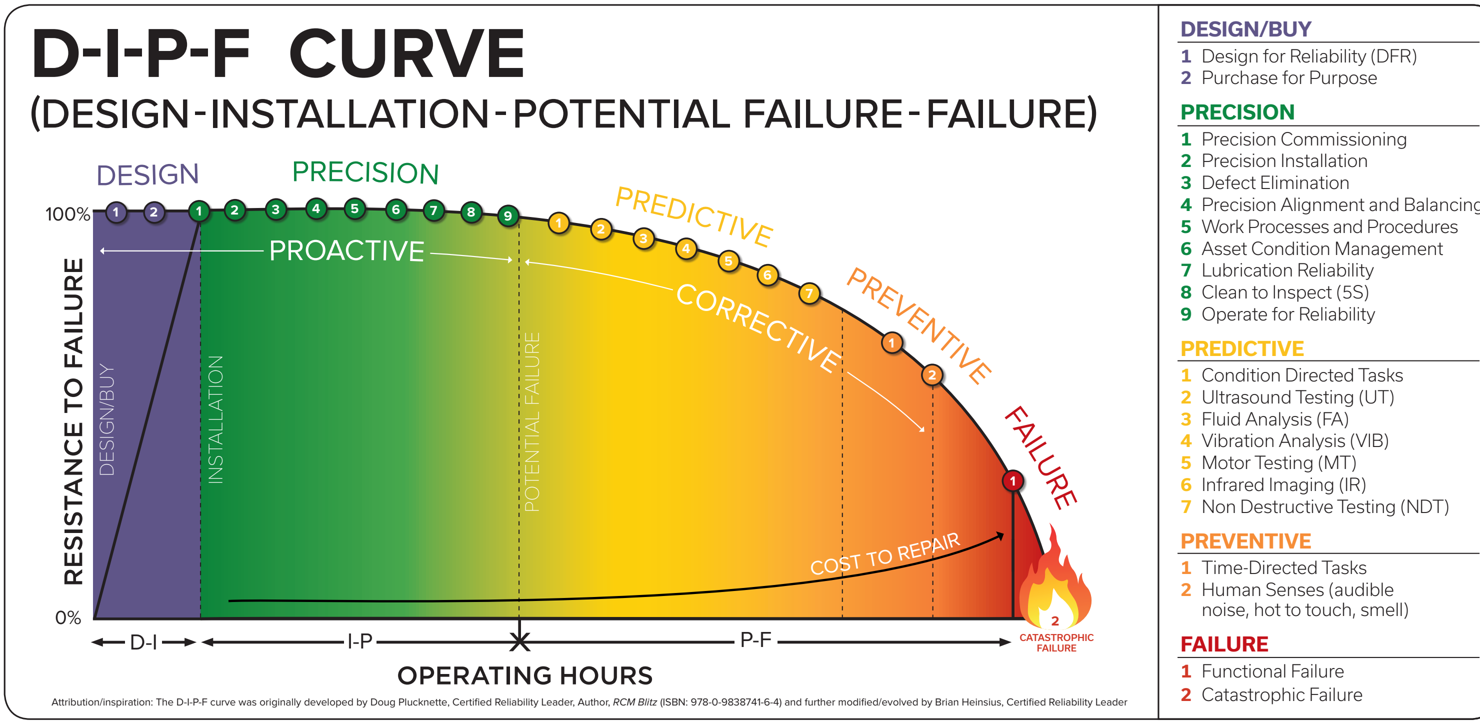


Figure 7: D-I-P-F curve as created by Reliabilityweb.com. Copyright 2016-2018. NetexpressUSA Inc. d/b/a Reliabilityweb.com. (Download this PDF: www.reliabilityweb.com/steal-these-graphics)

> "The most costly and dangerous place for a company to perform the majority of its maintenance work is in the reactive domain"

minute (GPM), it is functionally failed when it can no longer produce 120 GPM. It will still operate, it will still produce pressure and flow, but if you need 120 GPM and its only producing 119 GPM, it has functionally failed. Why is this important?

Understanding performance standards, functions and functional failures is what enables you to continue to supply your customers on a regular basis. Understanding functional failure is not only part of that, but it also helps you drastically reduce secondary damage to your equipment. If you can muster the discipline to replace or repair your equipment prior to functional failure, there should be little to no secondary damage AND you still should be able to supply your customers' orders.

THE REACTIVE DOMAIN

The most costly and dangerous place for a company to perform the majority of its maintenance work is in the reactive domain. Ten years ago, it wasn't all that uncommon to find companies whose maintenance workload was 70 percent reactive or more. While most have learned this lesson, there are still companies living this nightmare. Within one hour of walking in the door, the ugly signs of an organization in chaos begin to show up. There is a daily punch list in the maintenance supervisor's office; maintenance spending on spare parts is over budget; scheduled proactive events are often postponed; overtime is out of control; there is a high occupational safety and health administration (OSHA) reportable rate; and so on.

It has been documented that companies performing the majority of their maintenance in the reactive domain can expect a transition time of five to 10 years to become an organization that considers maintenance reliability a part of their capital improvement process.

If your organization is presently living in this domain, the question you should be asking yourself is: Will this company continue to survive another five or 10 years?

CONCLUSION

In the last 10 years, acceptance of the D-I-P-F curve has grown to a point where it is often referenced in articles on asset management and reliability engineering. Companies looking to manage the entire lifecycle of their assets can benefit from the tools and methods that can be used at each point of the curve.

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DEFECTS, P-F AND THE REST OF THE STORY

Joel Levitt

Think about all the initiator causes of failure that are not really related to maintenance. Initiator causes are those events, possibly microscopic, that initiate decay shown by the P-F curve. Examples of initiator causes might include heat, dirt, or overloading.

Figure 1 shows a P-F curve, with the arrow pointing to a potential failure that is precipitated by some initiator. This initiator can be microscopic, such as a piece of dirt, or macro, like a steel slab hitting the rollers off-center. Once the potential failure is realized or initiated, the march to destruction is inevitable. The only unknown is how long it will take. At this point, the only thing of interest is how soon the march to destruction can be detected.

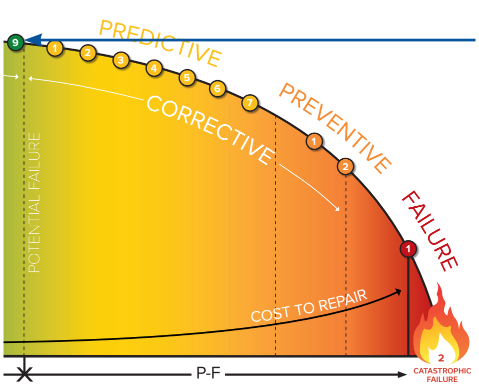


Figure 1: Potential failure shown on a P-F curve. Copyright 2016-2018. NetexpressUSA Inc. d/b/a Reliabilityweb.com.

Most often, the cause of the initiator is one of the five big sources of defects that lead to breakdowns. According to Winston P. Ledet, a consultant and workshop instructor on proactive manufacturing and maintenance and coauthor of the book, *Don't Just Fix It, Improve It!*, these defects are:

- Defects carried in on raw material 21%
- Defects in operation of equipment 29%
- Defects in the repair of equipment when maintenance is performed 21%
- Defects due to spare parts, materials and consumables used in repair 8%
- Defects due to equipment design or selection 21%

As you can see, 29 percent of the defects are due to maintenance causes and the rest are due to a small group of outside causes.

Because the sources are both inside of maintenance and, more commonly, outside of maintenance, it is correct to say:

- You can never preventive maintenance (PM) your way to reliability.
- You can never plan your way to reliability.
- You can never schedule your way to reliability.
- You can never invest or buy your way to reliability.
- You can never scan using any technology to reliability.
- **There is no silver, gold, or platinum bullet that will give you reliability.**

The reason is simple: Since the source is outside of maintenance, then it is likely that the solution must also be outside of maintenance. No pure maintenance solution will address even a simple majority of the causes of reliability problems. While this is true, it is not the whole story.

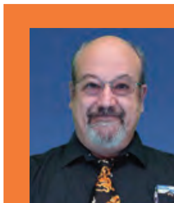
While the cause of the defect is outside of maintenance, mitigation of the defect is certainly inside of maintenance. For example, if a hidden rock comes into a sawmill inside a log, the defect's source is outside of maintenance, but the detection, mitigation and resolution is certainly within the scope of maintenance.

A multilayered defense is necessary. This approach is called defense in depth. If defects that are bad enough to disrupt reliability can come in from five sources, you must:

- Know your defects;
- Spend time eliminating defects that are present (i.e., defect elimination);
- Spend time eliminating sources of defects (i.e., root cause analysis);
- Spend time designing systems and procedures to detect, filter and mitigate the effects before they impact reliability (i.e., failure mode and effects analysis, preventive maintenance, asset condition monitoring, standard operating procedures, etc.).

This ability can be a competitive advantage. For example, an East Coast manufacturer makes small stampings. The company is very good at doing this, but even with skill, it is difficult to make much money since the material cost is 70 percent of the cost of goods sold (COGS). The manufacturer also had problems when the steel coils purchased were not pristine. Defects in the raw material were the biggest problem. Gradually, the manufacturer adapted the stamping tooling to accommodate the most common defects (i.e., variance in thickness, flatness, slight rust, etc.). To add insult to injury, sources in China and Asia were opening up, so there was already pricing pressure.

The manufacturer realized those common defects could be turned into a competitive advantage. Since its tooling could work with a wide range of defects in the coils, the company started to intentionally buy defective coils. The tooling could make good parts from coils that were slightly rusty, warped, too narrow for others, or designated scrap by larger manufacturers. Since the manufacturer could work with secondary coils, it dropped its COGS by 50 percent. This allowed the company to both compete and make an excellent profit. Today, the manufacturer is selling a selection of its products in China to be incorporated into their products.



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Aci asset condition information

ARTIFICIAL INTELLIGENCE:

A PRIMER FOR THE RELIABILITY COMMUNITY

Artificial intelligence or AI is the simulation of human intelligence processes by machines, especially computer systems. These processes include:

- **LEARNING** – the acquisition of information and rules for using the information;
- **REASONING** – using the rules to reach approximate or definite conclusions;
- **SELF-CORRECTION** – automatically making adjustments.

The human intelligence processes collectively are referred to as *cognition*. AI, therefore, can be defined as the *simulation and automation of cognition using computers*. Particular applications of AI include expert systems, speech recognition and machine vision.

AI, in itself, is a broad term that includes things like natural language recognition. Rule-based expert systems built in the past for industrial applications, including machinery health, are the simplest form of AI. In the context of the Industrial Internet of Things (IIoT), Industry 4.0, or Smart Industry, the specific subset of AI that is relevant is machine learning.

> "AI, therefore, can be defined as the simulation and automation of cognition using computers"

What Is Machine Learning (ML)?

Machine, in this context, is any computing system, from clusters of computers, often in the Cloud, to small sensors, more so in the future. People have been using computers for decades to solve problems. A program running on a computer, when given some inputs, provides an output. The programming technique used in this case is called explicit programming. It is explicit because a set of instructions is written (i.e., a program) that repeatedly solves the problem according to those instructions (i.e., logic). Two points to note about this type of computing:

- It is given a set of instructions by a human on how to solve the problem.
- It will not *learn* or get any better with experience.

ML differs from explicit programming in two ways:

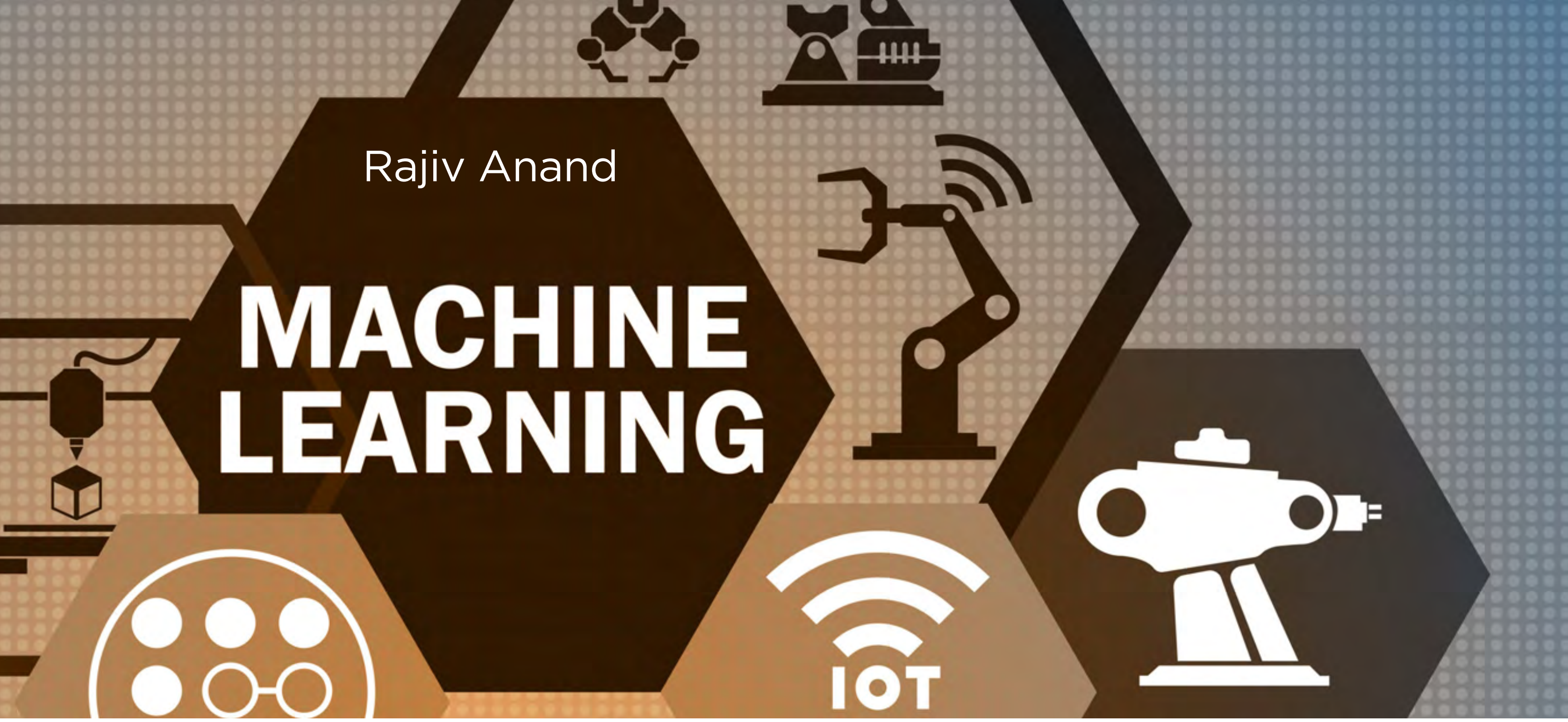
1. ML creates the program. This is referred to as an algorithm, a model and, sometimes, an agent learning from the data it is given.
2. Its ability to solve the problem gets better with experience. In other words, ML learns. Can you see the similarity to human learning?

How Does This Learning Happen?

Actually, not very different from humans: education (i.e., learning from examples), curiosity, intuition, experience, success (i.e., rewards) and failure.

Supervised learning

The learning by example method of ML is referred to as supervised learning. Humans provide the computer with a lot of data for the different attributes or variables related to an object (e.g., a pump) or a situation (e.g., cavitation). These attributes in ML are referred to as features. If you were creating an ML model to determine pump health, pressure, flow, vibration and temperature would be features. Now, let's say your algorithm was to detect when cavitation is likely to occur. You have a lot of historical data on different features and you have examples when cavitation happened. These examples are referred to in ML as labels. Certain correlations between the features start to occur when you are getting to cavitation. Shown enough examples of features and labels, the algorithm tries to approximate a function or, more simply, create a mathematical representation that can be used in the future to recognize similar correlations of features (i.e., patterns) to predict the outcome (cavitation). In "approximate a function," approximate is a key word. Most ML algorithms have their origins in statistics, so they are subject to such things as probabilities and approximation. How well will this function be able to detect patterns in the future that it has not seen explicit examples or labels for? In ML, the question is, how well will it generalize? That's where data scientists



add the magic, but the explanations might get too technical! However, the important things for asset experts to know are:

- For supervised learning, you need measurement of features (IIoT anyone?);
- A lot of data on the features;
- Labeled data on the situation (i.e., outcome).

The quantity and quality of data matters. If you've given too little data to the algorithm, it is likely not to generalize well or, as they say in ML, it will have a bias and bias leads to poor decisions. If the quality of data is bad, you will have trained your model on noise and the model will not be very accurate.

Unsupervised learning

What if you don't have a lot of labeled data? That's where unsupervised learning, akin to learning by curiosity in humans, comes in handy. Given a lot of data, the algorithm explores it and finds unique patterns or groups of feature correlations and can approximate a function to tell the difference between similar and dissimilar, normal and abnormal, and "belongs to the family" or is an outlier. As compared to supervised learning, a lot more data is generally required for unsupervised learning.

Unsupervised learning is commonly used for anomaly detection and outlier detection.

Deep learning

A specialized form of machine learning that doesn't use a statistical approach, deep learning mimics the workings of neurons in the human brain. Each neuron calculates a function, communicates the results to a neuron in the next layer (like synapses firing in the human brain), which then performs a calculation function, and so on, until an answer can be computed. Each layer has not just one, but multiple neurons and the output of any given neuron is given a significance or weight. Finding the right weights of specific neuron output in each layer determines the accuracy of the output. This is similar to the formation of human intuition and other cognition (e.g., object, color recognition). And just as with human intuition or cognition, it is not easy to interpret how the deep learning algorithm arrives at the answer. However, just like human intuition, it takes a lot of data to learn, is generally better at managing "noise" and can be highly accurate.

Deep learning is commonly used for image recognition and speech recognition.

There are a few other machine learning techniques, such as reinforcement learning and general adversarial networks, topics for subsequent articles.

Deployment

A model created using any of the previously described machine learning techniques is then connected to real-time process, electrical and condition data to provide real-time predictions. However, in order to qualify as a true machine learning based system, the model cannot be static; its learning must improve over time as it is exposed to new data and user feedback.

IIoT

So what does IIoT have to do with ML, or vice versa? You probably have the answer by now. To build a model for prediction (i.e., real predictive maintenance), you need features. These features come from sensors installed on the asset. And, IIoT is just a buzzword for sensors installed on industrial assets.

In the context of ML for asset condition management (ACM), sensors are not necessarily condition sensors, like vibration. Asset health prediction using ML can be done without any condition sensors for process induced failures, or combined use of process and condition sensors. It can also be applied simply to automate condition-based maintenance (CBM), like first pass analysis of vibration data.

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HABITS ARE THE BUILDING BLOCKS TO SUSTAINABILITY

Rick Wilke

What habits do you have at your workplace? What work habits do your peers have?

Habits can ruin your life or make it better. You choose which habits form your lifestyle, but can corporations choose the habits that form the behavior(s) present in its workforce?

Toyota was once again in the top 50 of the Forbes Global 2000: Top Regarded Companies ranking for 2017[1]. American companies did well, but most are not in manufacturing. Why?

U.S. companies continue to make management decisions based on return on investment (ROI) calculations and executives setting production targets (regarded as the GM management model). Middle managers chase these targets and do what they need to do to make their pivot charts and reports meet executive management's objectives. This is not what Peter Drucker had in mind in his book, *The Practice of Management*, when he outlined managing by objectives. The GM model is a short-term management goal and does not consider long-term sustainability. Toyota uses the ROI calculation to assist in determining how to obtain a desired condition, not for determining what to do.

Ford Motor Company once built plants that tried to achieve a contiguous flow. Toyota learned from this and, in trying to achieve a contiguous flow, developed a process of decision-making. Plan-do-check-act (PDCA) is a quality control tool made popular by Dr. W. Edwards Deming and is a solid foundation of this decision-making process. This process is a behavior taught and reinforced at Toyota. It is similar to how martial arts are taught by repeating proven techniques and form until it is natural to the student. This is known as kata. Sounds like forming a habit, doesn't it?

Since the 1970s, American manufacturing companies have been chasing Toyota in quality and efficiency. According to the Forbes Global 2000, they still are. Why?

LEADERSHIP: The days of GM style management are coming to an end. Sustainability will be the new model concept, with dynamic characteristics that adapt to each asset, each entity and each industry. Although profits, ROI and production goals are still very important, the focus will change to long-term contiguous, not continuous, flow in manufacturing. Amazon did not get to where it is today by trying to imitate Walmart. Rather, Amazon leadership recognized new shopping habits and capitalized on the opportunity. Amazon's leadership set sail on a new horizon and built a business based on what was on the horizon, not the body of water it was in.

MIDDLE MANAGEMENT: Once leadership is on board and has set sail toward a dynamic new world of contiguous flow, middle management needs to keep the ship afloat and on course. There will be storms, such as government regulations, taxes, stockholders, economy, competition, etc. The horizon may seem further away at times, but leadership must enforce the course/vision and middle management must enforce the work habits to get there. There are so many tools available today to manage assets. The International Organization for Standardization's ISO55000: Asset Management or similar management models give leadership and management guidelines to manage assets, whether it is people, intellectual property, machines, structures, etc. Six Sigma, lean management, reliability-centered maintenance, the Internet of Things and other tools are available to track, measure and document quality, production, maintenance and management metrics.

TRAINING: Train, cross-train and retrain. Always invest in training and improving people's skill level, work related or not. Nonwork-related training keeps people happy and motivated if the opportunity to learn/increase skill level is in something of interest to them. This usually pays off with higher employee morale and loyalty. Learning and developing skills is a habit you want employees to develop and transfer to work related skill development. Cross-train your employees in other areas. When a person of one discipline learns the day in the life of a person in another discipline, there is better respect and understanding between them. Cross-functional barriers are removed and cross-functional teams are created. Identify the habits required to obtain the behavior desired for each employee position and the company, then create training exercises to reinforce forming and keeping these habits. Think of habits as being the critical parts required for your human/company behavioral system and what is needed to keep this system running.

HIRING: Are you still hiring the same way and from the same pool of people you have been hiring from for 10 years and wondering why your results have not changed? Make a list of the skills, habits and traits for each position and hire people having those skills, habits and/or traits. Do not hire because they have experience in the industry. Older applicants who have a thirst for learning are great employees because they have a lot of developed skills, as well as the drive to learn new things. Previous small business owners who have successfully grown into a larger company tend to have the PDCA mentality. There are a lot of fish in the ocean and maybe you are fishing in a pond.

FEED THE FUNNEL: Be proactive with local school systems. Schools are the top of the funnel for future employees. If you want a great employee pool to choose from in the future, you better start today with making sure the proper skills and habits are developed early in the education system. The journey will be a long one if you are doing it right. Make sure your ship has the people it will need in the future to fulfill the voyage.

IMPLEMENTATION: Implement "The Toyota Way," the "Toyota Kata," or a master-mentor-apprentice training program. Each company needs to develop and teach a new process of problem-solving, critical thinking and continuous improvement until it becomes a habit instilled in each employee from the top to the bottom. Improvement, adaptation and change should be dynamic within a company. Employees at every level shall be a master, mentor and apprentice, all at the same time.

Change does not happen overnight. As the expression goes, the only way to eat an elephant is one bite at a time. Of course, the only way to create a new healthy habit is to break the old unhealthy habit. How do you do that?

1. Admit the current process is not sustainable and is a reaction to current conditions (e.g., management, economic, political, etc.).
2. Recognize that egos get in the way of progress. Put egos aside and the company's greater purpose first, once a new, contiguous flow vision has been identified. If there is no company, there will be no jobs.
3. Examine past behaviors (i.e., habits), rules, company policies, accounting, logistics, operations and maintenance procedures with the assistance of a third party. "This is how we have done it for years" needs to be abolished and silos destroyed. Fresh eyes from outside the industry will help.
4. PDCA: Start making changes, but monitor and learn from them. This includes managerial, operational, mechanical and behavioral changes.

5. Learn new habits. Each level of management and each employee at every level will need to learn new habits. The old way is over. Identify this new behavior pattern and train, enforce and act to support it. Get third-party support to assist in training, monitoring and changing until the core employees have made the new system a corporate habit. Review PDCA. Are you still heading to contiguous flow with these changes, behaviors and habits?
6. Help others who want to make a change. Go to seminars, workshops and conferences with like-minded companies within or outside your industry. This will provide a support group, but also a group that will be rich with ideas.

Change will not happen overnight. This is a long-term commitment for sustainability. Each company and each industry need to find its own path. What works for one place may not work at another. What works in one part of the world or country, might not work in another. PDCA starts with an individual and ends with the team. Creating new habits will, in turn, create new behaviors, which will lead to new beliefs, which will transform to a new company culture of sustainability! Set sail today and hope to see you on the horizon!

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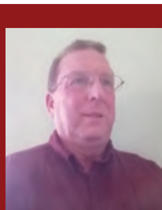

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DOES RELYING ON CRITICALITY PUT YOUR ORGANIZATION AT RISK?

Grahame Fogel and Petrus Swart

This article is Part 1 of a series focusing on risk as an enabler for asset management. It argues the case for moving away from criticality to an ISO31000 risk-based approach. Part 2 will address how to effectively model asset risk in complex systems.

The role of asset management (AM) as a strategic enabler contributing to the current competitive business landscape is rapidly evolving. The emergence of the AM professional has transitioned the maintenance engineer from a role whose primary responsibility is repair to that of a strategic value enhancer. This means AM professionals are now tasked with delivering strategic asset value contributions in alignment with their organization's overall business objectives.

On a weekly basis, these AM professionals are confronted with complex questions that require swift decision-making, followed by appropriate action.

Typical issues include:

- Will this asset or system last until the next scheduled shutdown?
- Should the asset/system be replaced in this budgetary cycle or the next?
- How should priorities change if the budget suddenly gets reduced by 10 percent?
- Which assets/systems are most critical to achieving business objectives?
- Which assets/systems are putting the achievement of business objectives at risk?
- Which assets/systems are most deserving of attention and limited resources?

These are all real-life issues that carry both strategic and tactical implications. Unfortunately, it is still prevalent today to see AM professionals devoid of any decision-making methodology that is aligned to asset value contribution and the achievement of organizational objectives. In other words, they do not have a standardized approach or framework from which to make effective AM decisions that will address these complex issues.

Effective decision-making requires both clarity and a structured approach. The goal of AM is to provide a clear set of principles that will guide the decision-making of AM professionals and organizations toward the achievement of their organizational objectives. ISO55000[1], the international standard for AM, recognizes risk as a cornerstone in creating an approach or framework to address AM related issues. It states that: "*AM translates the organization's objectives into asset-related decisions, plans and activities using a risk-based approach.*"

In this regard, a more incisive understanding of *risk*, as opposed to traditional *criticality*, and the application of a risk-based approach advocated by ISO55000 are key enablers for AM professionals to make more effective AM decisions.

Criticality is a non-normalized approach and often a vaguely defined concept that can mean different things to different AM professionals and organizations. Traditionally, it is a process that has been applied within the maintenance and engineering departments in isolation from organizational risk management frameworks. Criticality usually serves the function of maintenance prioritization, but is often ill-suited for providing the decision-making input to operational and strategic challenges where significant asset value can be unlocked.

Instead, an asset risk approach can be used by AM professionals to make more effective AM decisions. This approach is aligned to ISO31000[2], the international standard for risk management, and ISO55000. It contains the current best thinking around the topic of risk management and can assist AM professionals to better structure their operational and strategic AM decision-making efforts.

Effective risk management is a clear value enhancer for asset intensive organizations. This has been demonstrated by multiple published research articles by the Aberdeen Group[3]. Table 1 provides a summary of three of its research findings, demonstrating the clear value benefits of risk management programs at asset intensive organizations.

Moving Away from Criticality

It needs to be stated up-front that traditional criticality is not inherently bad or incorrect. Nor is its intentions flawed or completely misguided. Like most new ideas or schools of thought, traditional criticality experienced a few growing pains. Its synonymous growth with the field of AM has led to numerous individuals and institutions creating their own versions of criticality. Reviewing the published literature reveals several terms, such as *risk-based criticality analysis*[6], *multi-state component criticality analysis*[7], *analytic hierarchy process-based criticality analysis*[8], etc. This is not a negative issue as it shows the necessary thinking, development and refinement that has gone into criticality in recent years.

Similarly, prior to 2014, literature often referred to AM as *physical asset management*[9], *engineering asset management*[10], etc. The release of the ISO55000 suite of AM standards in 2014 has helped streamline the thinking behind AM. No longer do AM professionals fret over their version of the name, but rather focus on making AM a legitimate profession backed by a less disjointed and fractured body of knowledge (BOK). One glaring issue in the current AM BOK, however, is the use and continued misuse of criticality.

Literature on criticality is plentiful, diverse and oftentimes confusing. However, a particularly good read is "Criticality Analysis Made Simple" by Tacoma Zach[11]. Here, criticality is defined as: "*a measure of the relative importance of something, usually a tangible system or asset, to the corporate mission, objectives and values of your organization.*" The criticality of a system or an asset is determined by a criticality analysis, which is defined as: "*a way to determine which systems and assets are most essential in order to set priorities for further reliability initiatives and deeper analysis.*" These two definitions are clear with regard to the aspirations of criticality in general and what constitutes a criticality analysis. However, these definitions also unintentionally cause significant confusion for AM practitioners in the field and during robust online discussions.[12]

With criticality, confusion and common misconceptions rear their ugly heads on several issues. Most of these issues are adequately addressed in Zach's book. For example, it is made clear that an asset or system in critical condition (i.e., poor condition) does not correlate with its criticality to the function or mission of the system. However, the biggest source of confusion remains in the interchangeable use of the word criticality (or asset criticality) and other terms, such as risk and consequences. This is encountered habitually

Table 1 – Value Benefit of Top Risk Performers

Definition of Maturity Class	Mean Class Performance
Best in Class: Top 20% of aggregate performance scores	**1.5%** Unscheduled Asset Downtime **92%** Overall Equipment Effectiveness (OEE) **99%** Production Compliance **3%** of Revenue in Financial Loss in Past 12 Months
Industry Average: Middle 50% of aggregate performance scores	**6.6%** Unscheduled Asset Downtime **83%** Overall Equipment Effectiveness (OEE) **97%** Production Compliance **12%** of Revenue in Financial Loss in Past 12 Months
Laggard: Bottom 30% of aggregate performance scores	**14.8%** Unscheduled Asset Downtime **74%** Overall Equipment Effectiveness (OEE) **85%** Production Compliance **18%** of Revenue in Financial Loss in Past 12 Months

Combined from Shah & Littlefield[4], Hatch & Jutras[5] and Aberdeen Group

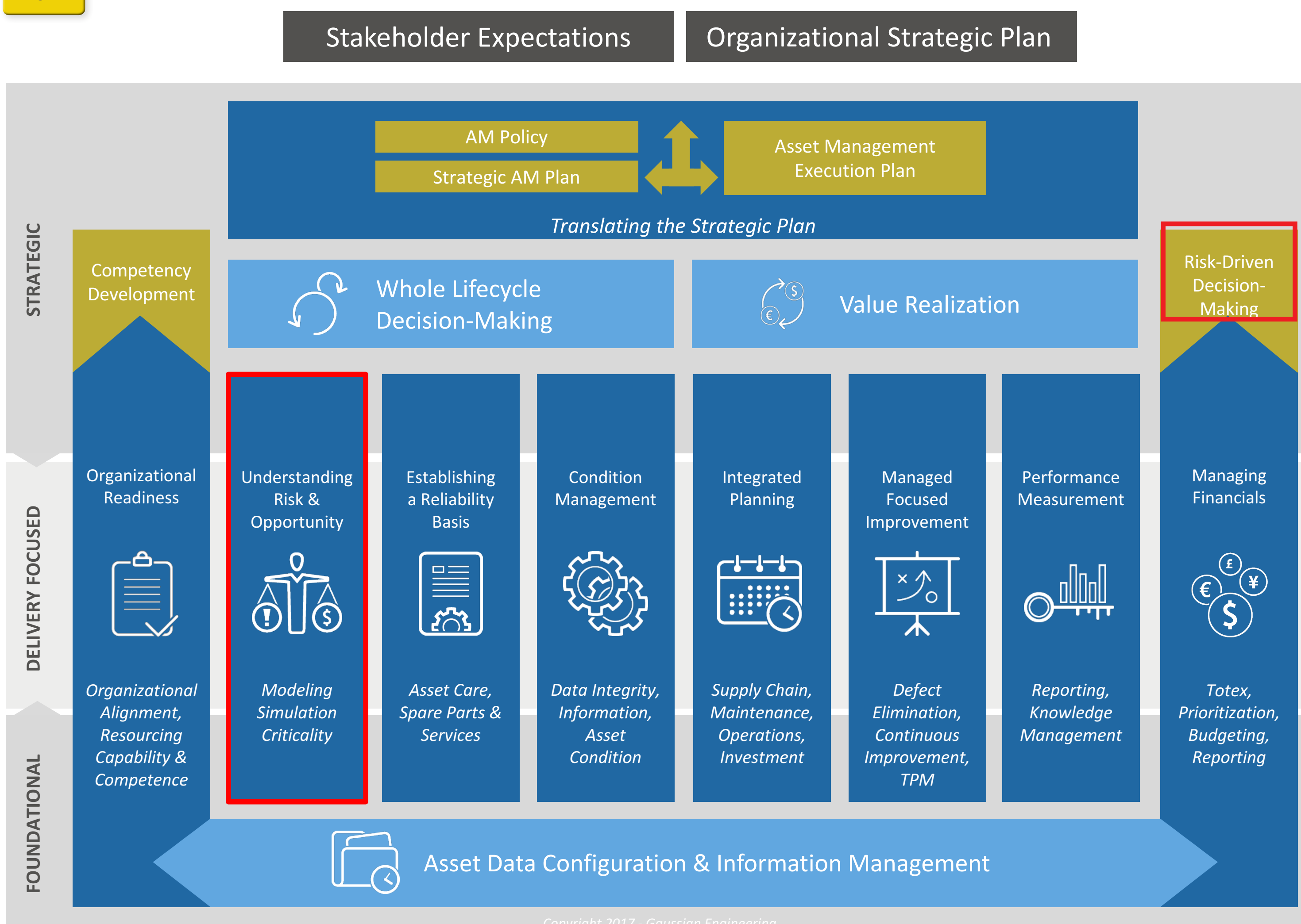

Figure 1: The Effective Asset Management Delivery Model (EAMDM)

when speaking to AM practitioners in the field and is widespread throughout literature.

Take, for example, critical assets. A typical definition would be: "*those assets with a high consequence of failure.*"[13] Here, the emphasis on what constitutes a critical asset is the magnitude of adverse effects that would proceed asset failure. This makes logical sense, however, the issue arises when one looks at the majority of criticality equations found in literature. Most sources mathematically express criticality as follows:

Criticality = Likelihood × Impact, or
Criticality = Probability × Consequences

Here, the criticality of an asset or system is simply the product of its probability of failure (PoF) and the consequences of failure (CoF). A highly critical asset or system, therefore, is one with a high PoF and high CoF, and vice versa, of course. The confusion, however, comes when one looks at established risk literature. Take, for example, ISO31000. Here, risk is expressed as: "*a combination of the consequences of an event and the associated likelihood of occurrence.*" In other words, according to ISO31000, risk is also mathematically expressed as:

Risk = Probability × Consequences

The inference here is that criticality and risk are the same thing, however, this is incorrect. A highly critical asset or system does not necessarily mean it is also a high-risk item, and vice versa. High voltage transformers are a popular example used to explain this point. Nowadays, most organizations rely on electricity to function, hence, the transformer providing the electricity is critical to that organization and the achievement of its objectives. However, transformers are generally very reliable, so they are not a major risk to the functioning of the organization and the achievement of its objectives.

It is this confusion with the word criticality, which is often glossed over or swept under the rug in AM literature, that necessitates the adoption of a risk-based approach that aligns to contemporary literature and the best thinking surrounding risk and risk management.

Adopting a Risk-Based AM Approach

Adopting a risk-based AM approach requires AM professionals and organizations to clearly understand the complexities of risk and its appropriate vocabulary. Furthermore, the difference between *asset risk* and *business risk* needs to be clearly defined and how asset risk supports AM needs to be crystallized. Finally, the adopted approach must align to ISO31000 and its structured risk management system.

Understanding the language of risk

All disciplines have their own vocabulary, so it is important for AM professionals to be conversant with the language of risk. This will facilitate cross functional understanding, discussions, learning and knowledge transfer between various departments internal to the organization, as well as with similar and different departments in other organizations.

ISO31000 defines risk as "*the* ***effect*** *of* ***uncertainty*** *on* ***objectives.***" Unpacking this broad definition reveals three essential words that need further clarification.

The first word is *effect*, which, from a risk sense, means a deviation from what one is expecting. It can be positive or negative. For example, a safety risk is almost always negative, whereas a financial risk may be positive when an asset operates long past its predicted end of life. Defining risk clearly is foundational to an organization's strategic criteria. This helps create an aligned risk framework from which risk-based decisions can be made in line with the organization's risk appetite. Once the framework is defined, both the positive and negative effects can be modeled.

The second word is *uncertainty*. In the real world, everyone lives with risk since the myriad of actions they participate in are bounded by uncertainty. It is brought about by the lack of information or knowledge concerning an event, its consequences and/or its likelihood of happening. With available knowledge or resources, any risk framework can clearly define the bounds of uncertainty and review actions that narrow these bounds in order to provide improved certainty in targeted areas.

Finally, organizations have both formal and informal *objectives*. Risk management aligns with and supports the achievement of these organizational objectives. This takes one from the operational to the strategic domain and is much larger than a maintenance priority listing. It is imperative to align the risk framework to these organizational objectives. The risk framework then can be applied to decision-making at a strategic, transactional, or project-based level, with clear transparency as to how those decisions are made.

What is asset risk and how does it support AM?

For asset intensive organizations, risk can be broadly categorized as either business risk or asset risk. Maintenance engineering expert Keith Mobley provides a good description of the differences between these two risk categories. In short, business risks refer to political shocks, market losses, business continuity, etc. On the other hand, asset risks refer to those surrounding the installed asset base or asset portfolio of the organization.[14] The focus of this article is on the latter risk category.

> ISO31000 defines risk as "the **effect** of **uncertainty** on **objectives**"

Risk forms an integral part of AM. The ISO55000 suite of AM standards contains many references as to why risk and a risk-based approach are important and necessary. This is exemplified in Section 6.1: Actions to address risks and opportunities for the asset management system in both ISO55001[15] and ISO55002[16], which are dedicated to the topic of risk.

The importance of risk in the field of AM is reinforced by the Effective Asset Management Delivery Model (EAMDM)[17], as shown in Figure 1. The EAMDM shows that risk is strategic and delivery focused, as well as foundational. This means the delivery of effective risk management activities needs to be guided by the organization's objectives in order to facilitate the achievement of these strategic goals. At the same time, foundational enablers, such as good quality asset data configuration and information management, are pivotal in enabling a sound basis from which to make evidence-based, risk-driven decision-making. Lastly, risk is delivery focused, which means it should be thought about and executed daily as risk is dynamic and can rapidly turn for the worse.

ISO31000 risk management system

The relationship between the principles for managing risk, the framework in which it occurs and the risk management process described in ISO31000 are shown in Figure 2. Here, the principles provide the foundation and describe the qualities for effective risk management within an organization. They guide the creation of the risk management framework. In turn, this framework defines and manages the overall risk management process and its full integration into the organization. Lastly, the process for managing risk focuses on individual groups of risks, their identification, analysis, evaluation and treatment. The performance of the process is monitored and fed back into the framework, making the process a continuously improving and iterative cycle.

Key Takeaways for AM Professionals

The discipline of AM has evolved rapidly in the last few years. Unfortunately, some areas of the AM BOK have not kept up with this frenetic pace of change. A notable example is criticality and its continued use and misuse throughout literature. The confusion surrounding criticality is largely due to its synonymous use with risk, as well as the fact that both terms have an identical mathematical expression.

This article, Part 1, highlighted the confusion and calls for AM professionals to move away from criticality and to adopt a risk-based approach. Moreover, it establishes the importance of asset risk and how asset risk supports effective AM. This

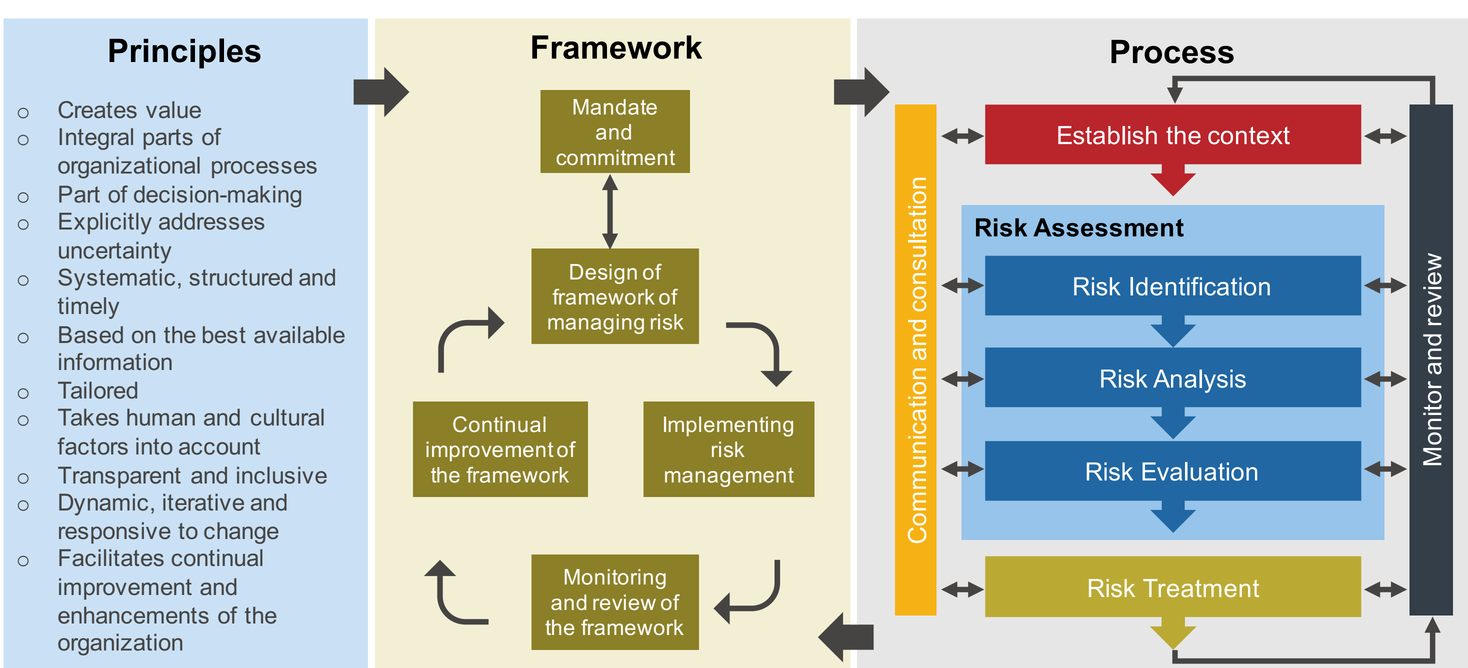

Figure 2: ISO31000 risk management system

point was emphasized by two international AM standards, namely ISO55001 and ISO55002, which both have a section dedicated to the topic of risk. To avoid any unnecessary confusion with criticality and to align with the international standard for risk management, ISO31000, a risk-based approach to asset risk was proposed as a solution.

Part 2 will describe an approach to asset risk that can help AM professionals and asset intensive organizations make better risk-based AM decisions.

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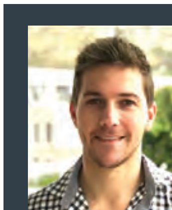

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It’s not about the
color of your collar…
It’s about how far you are
willing to roll up your sleeves.

Mro
mro-spares management

THE MRO DILEMMA: MAJOR TIME, MINOR SPEND

George Krauter

A universal situation in the world of the maintenance, repair and operations (MRO) supply chain is that managing the process consumes an inordinate amount of time from all plant departments. The MRO spend is only six to 10 percent of a plant's total, but it absorbs 70 to 80 percent of all transactions and causes 50 percent of the emergencies affecting plant reliability.

Many companies apply improvement ideas outlined in multiple publications, so, why then, do the conditions continue to exist? The lack of effectiveness comes from the fact that plant disciplines are multiple and varied. Many have ideas on how to run the MRO operation and which suppliers to use based on how the MRO process affects their individual job performance. Improvement ideas are often met with resistance and ongoing "MRO spats" cause any discussion about change to be sidelined. Managers give up on the MRO change opportunity and instead tackle other improvements with a better chance to bear fruit. Ironically, major deterrents to MRO improvements are production emergencies caused by unreliable MRO. There is no time to consider MRO supply chain improvements because of the existing MRO problems.

In a typical MRO storeroom, a company incurs significant costs to have parts on hand when needed. These costs are shouldered to ensure plant assets are reliable, facilities are maintained and safety regulations are satisfied.

THESE COSTS INCLUDE:

1. **FINANCIAL IMPACT:**
   - Price of parts;
   - Cost of inventory;
   - Freight;
   - Direct personnel costs (e.g., storeroom personnel);
   - Indirect personnel costs (e.g., paper processing and chargeback accounting).
2. **NONFINANCIAL IMPACT:**
   - Extended downtime;
   - Management opportunity costs;
   - Worker inefficiencies;
   - Incorrect parts;
   - Duplicated / uncontrolled substocks.

Since MRO constitutes just six to 10 percent of a company's total expenditure, the ineffectiveness of MRO supply chain management exists without recognition that there is considerable value that can be released from MRO operations. On a percentage basis, MRO contains the highest level of cost reduction available. How? First, take the costs assumed from financial impact.

Price is the area most often addressed by cost reduction programs. Actually, price reductions are near the low-end of recoverable MRO values. Parts are issued (i.e., sold) at the purchase price with no markup. The storeroom is a "store" and any store selling (i.e., issuing) material without markup loses money; therefore, the existence of a company-owned MRO storeroom is a profit drain.

> In a typical MRO storeroom, a company incurs significant costs to have parts on hand when needed

Why is price the king in selecting a supplier?

The answers are:

1. Price comparisons are among the easiest and best ways to measure value.
2. Price is the way management measures purchasing performance.
3. Management directs purchasing to buy for less, even if cheaper parts cause higher total costs.
4. Inventory: Generally, MRO inventory turns less than once per year. The MRO storeroom is a *store*, so how can a store return a profit with negative inventory turnover?

Why is this inventory turnover situation allowed to exist?

1. The threat of downtime caused by a lack of parts availability justifies increasing minimum/maximum order levels just in case something goes wrong.
2. Minimum/maximum order levels are rarely adjusted, even when a particular part is no longer or rarely used.
3. Duplicate parts exist under different descriptions and different SKU numbers, causing duplicated and excessive inventory levels.
4. Obsolete inventory recovery programs are not instigated, mainly because maintenance is reluctant to get rid of parts it may need and finance is reluctant to absorb a negative hit to the balance sheet when MRO inventory is considered an asset.
5. Incoming freight: You now have a desirable freight agreement, so why not use it with your supplier?
6. Direct personnel: Who issues purchase orders? Is the order already placed before purchasing gets it? Do you really need all the parts requisitioned? Are the descriptions accurate and consistent? Did you get the correct part?

MRO procedures are rarely adjusted because MRO is at the tail end of priority consideration; there is no time to consider change and there is little agreement as to what the change should be.

With regard to indirect personnel costs, generally, transactions involving MRO parts are 80 percent of all transactions processed and less than 10 percent of total dollars spent. Transactions can be consolidated by installing a single MRO source with semimonthly audit trails.

Next, look to nonfinancial impacts. Any one of the following can exceed all the costs listed in the financial impact list.

- **DOWNTIME:** The cost of an asset with downtime is excessive and affects all production performances.
- **OPPORTUNITY COSTS:** What values could be realized if time spent on MRO problems could be recovered and reallocated?
- **IDLE WORKERS:** How much does it cost to pay a worker to do nothing?
- **INCORRECT PARTS:** You thought you had the right part, but you don't, so emergency shipments and emergency pricing abound. More downtime, more idle workers.
- **DUPLICATED SUBSTOCKS:** You have substocks for parts because the storeroom is unreliable, which creates an unnecessary burden on budgets. What could you do with added budget dollars if you did not need these substocks and could rely on an efficient MRO stores operation?

How can you take the actions necessary to resolve the MRO dilemma? Do you have time to do it yourself? Do you have the knowledge or expertise to implement and sustain a plan that would succeed? Even with the necessary experience and incentive to change, disciplines generally do not interact with each other, meaning MRO procedures are subject to the quirks of stakeholders with different priorities. Stakeholders are among the major reasons why the condition continues to exist.

There are many articles, blogs and books on MRO espousing procedures that would save money, release time for more important issues, improve procedures, increase reliability, etc. However, you are still spending time on your MRO supply chain. By employing some of the recommended improvements, benefits can accrue, but your MRO problems will still exist and you will not be at optimum.

Why do it at all? Because the optimum solution exists. Get out of the MRO business! Let an expert do it. Here's how:

- Select one supplier who will share all costs and has the experience and the commitment to succeed. Make sure this supplier has a successful implementation department and is flexible enough to meet the needs of all plant MRO functions.
- The supplier must offer asset management services, SKU analysis and computerized maintenance management system (CMMS) capabilities and have a corporate commitment for success in on-site MRO supply chain management.
- Tell the supplier the price you will pay that meets your price reduction goals; do not go out on quote.
- Write a statement of work with your selected supplier that solves your MRO supply situation.
- Require key performance indicators (KPIs) with incentives that ensure success.
- Get cooperation and buy-in from all plant disciplines.
- Implement properly! Poor implementation is a major cause of failure.
- Audit, measure, report and sustain.

By doing so, you now have the time to get on with your core business opportunities – your areas of expertise. Your MRO situation is solved at optimum total cost of ownership (TCO). You are relieved of the malignancy of MRO while obtaining world-class control of MRO contributions to plant reliability.

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Rca
root cause analysis

SOME PLAIN TALK ABOUT NUTS AND BOLTS

Neville W. Sachs

Part 1 of this two-part Q&A series covered torque specifications, why good tightening practices are important and fastener identification. This next Q&A provides detailed information answering frequently asked questions about the hardware to help you understand what is involved with quality bolting practices.

Q. How many threads of engagement are really needed?

A. A very safe answer to that is a full nut, but, in reality, some codes allow the bolt to be one thread below the surface of the nut. Other codes, such as the compressed gas code, say there has to be two threads sticking out of the nut, but that's just to allow easier inspection because additional threads do nothing to add to the strength of the assembly.

A safe rule of thumb to follow when bolting into a weaker material, such as aluminum or cast iron, is to have at least one bolt diameter of engagement. But with very weak materials and older machinery that may have worn threads from years of maintenance, it is a good idea to have at least one and a half diameters of engagement.

Numerous tests have been conducted that try to induce failure from bolts stripping out of nuts that have been machined thinner. Based on these tests, the idea of one thread less than a full nut gives a reasonable safety factor.

Q. Does the nut have to be matched to the strength of the bolt?

A. Yes, but nuts and bolts have very different failure mechanisms. The bolt fails in simple tension, while the nut fails when the resolved forces on the threads cause the nut to grow larger until the tips of the threads strip. With the difference in mechanisms, a nut made from an identical material is inherently much stronger than the bolt.

On low strength or unstrengthened bolts, essentially any nut can be safely used. With Grade 5, A325 and metric 8.8 bolts, low strength nuts can be safely used unless the code prohibits them. With the stronger Grade 8, A490 and metric 10.9, high strength nuts have to be used and these bolts can strip the threads out of mild steel nuts.

Also, note that all metric nuts and all heat treated U.S. thread nuts have grade identifications stamped on them.

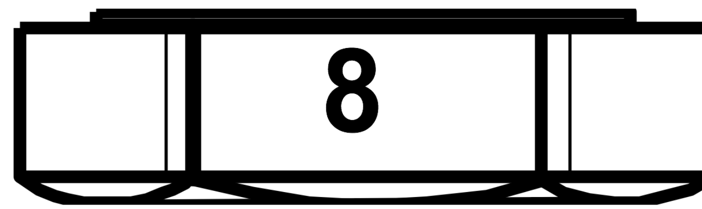

Figure 1: Example of a strength grade listing on a nut

Q. How are strength grades marked on nuts?

A. On metric nuts, there should be a number on the side that corresponds with the tensile strength. Figure 1 shows a nut marked with an 8, which means this nut would be used on an 8.8 bolt.

U.S. nut identification is more confusing because there are four different systems used, as shown in Figure 2. The key to understanding nut markings is to go back to the SAE International system for bolt identification. If there is no identification on the contact face, the nut is for low strength steel bolts. The two nuts on the left in Figure 2 have markings that are 120 degrees apart, similar to the lines on the head of an SAE Grade 5 bolt, so that is their strength level. Similarly, the two nuts to the right have markings 60 degrees apart, the same as a Grade 8 bolt. There are also nuts stamped with a 2H and they are designed for structural applications where A325 bolts are used.

Q. Is there reason to be concerned about counterfeit bolts?

A. Not really. Hardly anyone counterfeits $1 bills and, in a similar manner, there is little incentive to counterfeit low value fasteners. There are lots of very expensive defense and aerospace fasteners that are likely targets, but

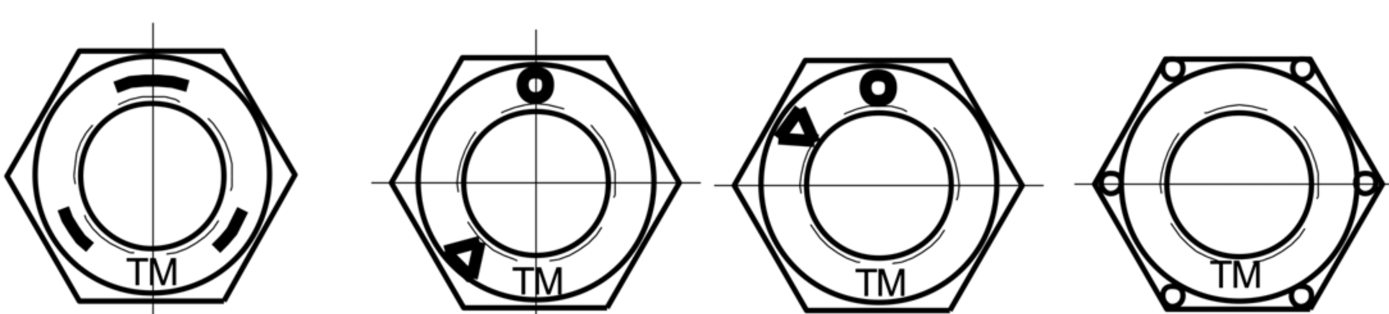

Figure 2: Example of the four U.S. nut identification systems

the equipment used in industry generally has relatively low cost and low technology fasteners that don't make good targets.

Having said that, about 15 years ago, some SAE Grade 5 bolts were found to be counterfeit. The offender had taken ordinary Grade 1 bolts and restruck the heads, making the familiar three line imprint of a Grade 5 bolt. Mismarked bolts also have been seen, where a quality manufacturer will accidentally mix in a bolt with inferior properties. But that is also rare.

Q. Where should washers be used?

A. Just about everywhere. In the long run, they do a great job in improving reliability. They insulate the bolting surface from the direct rotation of the bolt head or nut and help maintain that surface in good condition. They distribute the load over a greater area and they reduce friction forces.

Although the washer's primary job is to distribute the bolt load evenly over a larger diameter than the bolt head alone, the fact that it maintains the bolting surfaces in good condition is important because of the relatively small distances involved in the elastic elongation of a fastener, as shown in Figure 3 and Table 1.

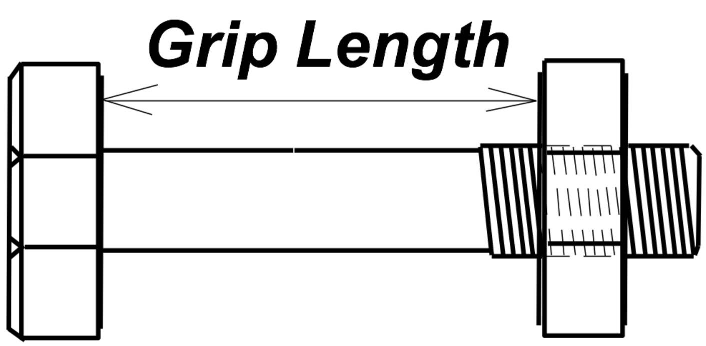

Figure 3: Example of the grip length shownning the distance between the two contact surfaces

Table 1

Fastener Grade	Elastic elongation	
	in/in	mm/100mm
SAE 1, A307, metric 4.8	0.001	0.04
SAE 5, A 325, metric 8.8	0.002	0.08
SAE 8, A 449, metric 10.9	0.003	0.012

So, if you are using an A325 bolt and the grip length is two inches (51mm), the elastic elongation is only 0.004" (0.08mm). If the washer you are using is bent, looks like a potato chip, or has worn rings on it, you know it can't possibly do its job properly. It has to be replaced with either a heavier or a harder washer to maintain the flatness and the quality of the bolting surfaces.

Q. Are hardened washers really necessary?

A. It depends on the application. If you use a Grade 8 or metric 10.9 bolt with yield strengths in the range of 120,000 psi, then really tighten that bolt up against a mild steel washer with a yield strength of 30,000 psi, you know that weak washer is going to be plastically deformed.

Even Grade 5, A325 and 8.8 bolts are more than twice as strong as the typical inexpensive washer and tightening them against the softer washer will badly gouge it, resulting in less uniform clamping forces.

Q. What happens to a bolt when you weld on it?

A. The result depends on the bolt's grade and when it was welded. If you take a heat treated bolt, such as an SAE Grade 5 or 8, or metric 8.8 or 10.9, and weld on it, you've changed the heat treatment, so you have no idea of the new strength. In addition, there may be residual stresses that could contribute to the stress in the bolt. Take, for example, a 20-ton crane hook where the repairman welded the nut to the hook to make sure it didn't come loose. The crane hook was made of the same alloy as many Grade 5 bolts. The heat from the welding changed the metallurgy of the steel and resulted in residual stresses that caused the hook to fail when picking up only 2,000 pounds. Therefore, the recommendation is to never weld on a heat-treated bolt.

> "...Never weld on a heat-treated bolt"

But, if you weld on Grade 1 or 2, or metric bolts 5.8 or lower, you can't do any metallurgical damage.

However, regardless of the grade, if the bolt has already been tightened, welding heats the bolt and tends to stress relieve it. Experiments conducted with a bolt testing device found that even a tiny amount of welding tends to reduce the clamping force by a factor of 50 percent, greatly increasing the chance for a fatigue failure.

Q. When should lock washers be used?

A. Certainly, there are some times, such as on soft gasketed joints and with bolted timbers, where lock washers improve the reliability of the joint. But, on hard gasketed joints or rigid metal to metal joints, lock washers rarely help joint reliability.

Bolted joints are designed so the clamping force of the bolt is greater than the separating force. The maximum clamping force that can be developed by a typical lock washer is only about 20 percent of the bolt's clamping force. Many star washers or multiple tooth lock washers can't deliver even that much clamping force.

So, what should you do instead to reduce the chance of bolt loosening? Use elastic stop nuts, self-locking nylon patches that bond to the threads of a fastener, or a thread-locking fluid, all of which provide resistance to the initial loosening, as well as continued resistance if the nut works loose.

There are also other fastener locking systems that consist of proprietary locking washer assemblies. They all have advantages and disadvantages, but almost all of them are far superior to split ring lock washers.

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Vernon Welch
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Eli Lilly
Craig Werner
Kaiser Aluminum
John Whitehouse
Kaiser Aluminum
Brandon Wilhelm
CBRE
Brian Young
Jacobs Technology

Rj reliability journey

WHAT'S IN YOUR DNA?

Terrence O'Hanlon

Uptime® Elements – A Reliability Framework and Asset Management System™ uses mental models and systems thinking to ensure a consistent language of reliability is embedded in the culture.

Mastery of anything begins with the acquisition of a specialized language. From gourmet cooking to fly-fishing to brain surgery, each has a language. The same holds true for those who wish to master reliability leadership and asset management. Language in this case is not simply words, it also includes phrases, sentences, concepts and paragraphs. Metaphors can be powerful in helping people grasp complex topics because they use concepts and models that are already familiar.

> "Mastery of anything begins with the acquisition of a specialized language"

Reliability DNA

A new visual model, called Reliability DNA, was recently introduced to enhance the adoption and understanding of the Uptime Elements – A Reliability Framework and Asset Management System.

As you know, deoxyribonucleic acid (DNA) is an essential molecule for life. It acts like a recipe, holding the instructions that tell our bodies how to develop and function.

Likewise, Reliability DNA is essential for organizational life. It acts like a recipe, holding instructions that tell stakeholders how to develop and function.

DNA is a molecule that carries genetic instructions used in the growth, development, functioning and reproduction of all known living organisms and many viruses.

Similarly, Reliability DNA is a framework that carries the instructions used in the growth, development and functioning of each stakeholder in your organization.

An important property of DNA is that it can replicate or make copies of itself. Each strand of DNA in the double helix can serve as a pattern for duplicating the sequence of bases. This is critical when cells divide because each new cell needs to have an exact copy of the DNA present in the old cell.

An important property of Reliability DNA is that empowerment and engagement based on a common language and framework can serve as a pattern for duplicating the sequence of cultural adoption. This is critical when the organization expands and adds new people because each new person needs to have an exact copy of the Reliability DNA framework that is present in the existing culture.

Cells get their instructions on what to do from DNA. DNA sort of acts like a computer program. The cell is the computer or hardware and the DNA is the program or code.

In organizations, people get their instructions on what to do from the Reliability DNA. The Reliability DNA framework sort of acts like a computer program. The organizational culture is the computer and the Reliability DNA is the program or the code.

Holding the nucleotides together in DNA is a backbone made of phosphate and deoxyribose. These nucleotides are sometimes referred to as bases.

Holding the Uptime Elements together is a backbone made of integrity, authenticity, responsibility and aim, referred to as reliability leadership.

Healthy Reliability DNA includes 36 elements from five different knowledge domains:

1. **Reliability Engineering for Maintenance;**
2. **Asset Condition Management;**
3. **Work Execution Management;**
4. **Leadership for Reliability;**
5. **Asset Management.**

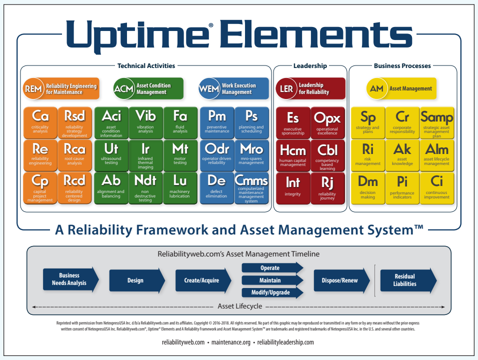


Figure 1: The Uptime Elements chart

THE INDIVIDUAL ELEMENTS OF RELIABILITY DNA ARE:

- criticality analysis;
- reliability strategy development;
- reliability engineering;
- root cause analysis;
- capital project management;
- reliability-centered design;
- asset condition information;
- vibration analysis;
- fluid analysis;
- ultrasound testing;
- infrared thermal imaging;
- motor testing;
- alignment and balancing;
- nondestructive testing;
- machinery lubrication;
- preventive maintenance;
- planning and scheduling;
- operator driven reliability;
- mro-spares management;
- defect elimination;
- computerized maintenance management system;
- executive sponsorship;
- operational excellence;
- human capital management;
- competency-based learning;
- integrity;
- reliability journey;
- strategy and plans;
- corporate responsibility;
- strategic asset management plan;
- risk management;
- asset knowledge;
- asset lifecycle management;
- decision-making;
- performance indicators;
- continuous improvement.

REACTIVE DNA IS GENERALLY UNHEALTHY FOR ORGANIZATIONS AND RESULTS IN:

- Reactive maintenance;
- Unexpected breakdowns;
- Out-of-date criticality ranking;
- Poor communication;
- Unclear objectives;
- Missing procedures;
- Habit based maintenance;
- Poor operator training;
- Work that is disconnected from the aim;
- Missing line of sight;
- Missing cross-functional collaboration;
- High turnover;
- Lack of engagement at the front line;
- Poor lubrication practices;
- Unknown failure modes;
- Predictive maintenance pretenders;
- No defect elimination;

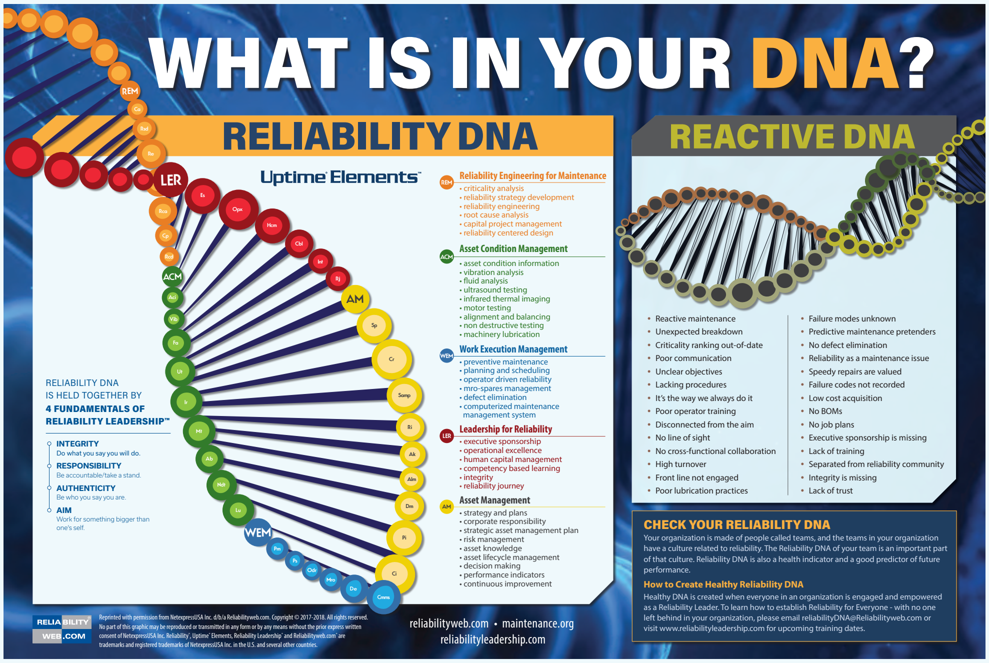
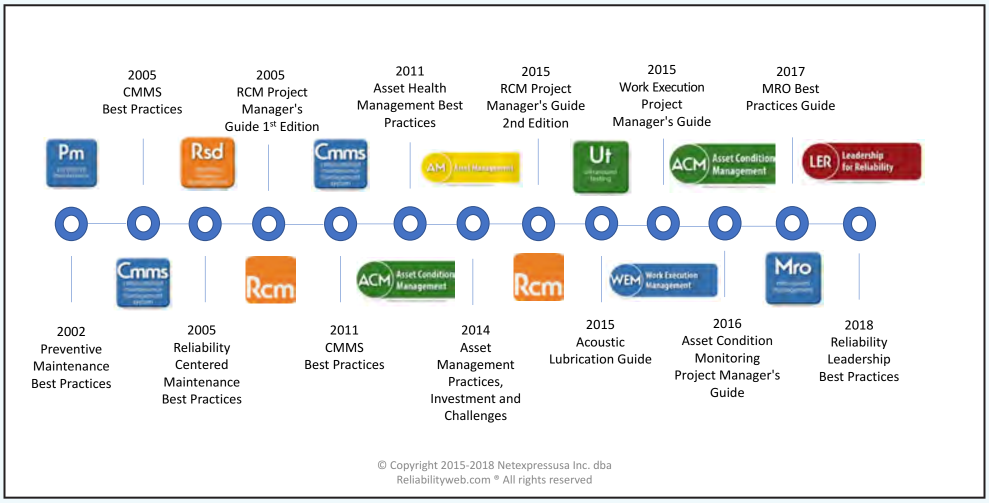


Figure 2: Reliability DNA. Copyright 2017-2018. NetexpressUSA Inc. d/b/a Reliabilityweb.com.



ISO International Organization for Standardization | SAE INTERNATIONAL | IEC International Electrotechnical Commission Compliant

- ✓ ISO55000 Asset management -- Overview, principles and terminology
- ✓ ISO55001 Asset management -- Management systems – Requirements
- ✓ ISO31000 Risk management -- Principles and guidelines
- ✓ ISO14224 Collection and exchange of reliability and maintenance data for equipment
- ✓ ISO17359 Condition monitoring and diagnostics of machines -- General guidelines
- ✓ ISO13372 Condition monitoring and diagnostics of machines – Vocabulary
- ✓ ISO18436-8 Condition monitoring and diagnostics of machines
- ✓ Requirements for qualification and assessment of personnel
- ✓ IEC60300-3-11 Dependability management -- Part 3-11: Application guide -- Reliability centered maintenance
- ✓ SAE-JA1011 Evaluation criteria for reliability centered maintenance (RCM) processes
- ✓ Many more…

Figure 3a & 3b: The Uptime Elements - A Reliability Framework and Asset Management System is based upon industry research and international standards

Figure 4: Reliability Leadership Institute group meeting

- Reliability as a maintenance issue;
- Speedy repairs are valued;
- Failure codes not recorded;
- Low-cost acquisition strategy;
- No bills of materials (BOMs);
- No job plans;
- Executive sponsorship is missing;
- Lack of training;
- Separated from the diverse reliability community;
- Integrity is missing;
- Lack of trust.

Uptime Elements – A Reliability Framework and Asset Management System, available in English and Spanish, is used to create engaged and empowered reliability leaders at over 1,800 organizations around the world.

It is based on the deepest body of longitudinal research in the industry, conducted from 2002 to 2018, and is designed to align with a framework of International Organization for Standardization (ISO) standards, such as ISO55001, ISO31010, ISO14224, ISO18436 and several others. Over 600 assessments from Uptime Award nominees, who are at the top level of performance, have also contributed to the studies.

There is an active peer-to-peer community of practice that not only uses Uptime Elements – A Reliability Framework and Asset Management System, but shares results from their 3 Month Orbits (i.e., single element focused projects) with each other, resulting in accelerated learning and adoption, especially when compared to isolated reliability champion approaches most organizations attempt.

Global use of the Uptime Elements framework as the primary strategy guide is embedded in numerous companies and organizations.

- Goodyear
- Honda
- Boeing
- CBRE
- PRUFTECHNIK
- Bristol-Myers Squibb
- Medtronic
- B. Braun
- Siemens
- Metropolitan Transportation Authority (MTA)
- DC Water
- Jacobs
- CH2M
- Metropolitan Sewer District of Greater Cincinnati (MSD)
- Gwinnett County Water
- Arizona Public Service
- Central Arizona Project
- Metropolitan Council
- Abbott
- Leprino Foods
- SDT Ultrasound Solutions
- Ultrasound Institute
- JLL
- Bentley Systems
- ARMS Reliability
- Life Cycle Engineering
- IRISS
- BNSF
- Corbion
- Kaiser Aluminum
- Many more…

Recently, an Uptime Elements Black Belt program was introduced to encourage deeper, action-oriented engagement and accomplishments related to advancing reliability and asset management.

Figure 5: Uptime Elements Black Belt Program

What Is in Your Organization's DNA?

There may not be much you can do about your own DNA, but you are in full control of your organizational DNA. You can use the Uptime Elements – A Reliability Framework and Asset Management System to create a future that was not going to happen anyway.

You can use it on your own through self-study by reading the Uptime Elements Body of Knowledge or utilizing the Uptime Academy online learning management system. You also can participate through formal training by attending one of the Certified Reliability Leader Advanced Workshops. You can even join the Reliability Leadership Institute® to engage in a peer-to-peer cohort.

The point is – get started. The reliability journey is an individual journey and it begins with you.

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Aci asset condition information

THE NEXT GENERATION OF MAINTENANCE RELIABILITY

Connected and integrated tools, sensors and software provide maximized uptime

Frederic Baudart

As industrial production rapidly transforms, the Industrial Internet of Things (IIoT) drives plant-wide changes and enhanced asset health and maintenance management. Facility managers, engineers and technicians must be able to rely on their equipment's operation. Monitoring assets and assessing their health is of paramount concern to detect problems before catastrophic failures.

Smarter decisions—guided by fast, accurate measurements—before maintenance, repair, or replacement activities can mean sizable cost savings, improved equipment operation and reduced safety risks. In best practices facilities, reliability inspections and monitoring optimize efficiency by reducing unplanned maintenance hours and diminishing the need for route-based maintenance in favor of condition-based maintenance triggered by changes in performance data. In an ideal situation, owners and managers can:

- Collect, store and group data;
- Track key parameters and capture faults;
- Tie readings to assets and work orders;
- Provide history;
- Receive alarms and provide notification.

Of the estimated 1.3 million industrial plants worldwide, 70 percent are more than 20 years old. Each facility includes numerous unmonitored tier two assets (compared to industry best practice of 80 percent monitored machines) and, most importantly, at least seven to eight critical assets that are unmonitored or not regularly inspected. That leaves several million unmonitored, uninspected assets that could benefit from asset health and performance data, now made feasible by connected, cost-effective maintenance technology.[1]

> Monitoring assets and assessing their health is of paramount concern to detect problems before catastrophic failures

Filling the Gap

The return on investment (ROI) and benefits of reliability and condition-based maintenance have been known for decades, but only recently have technologies come together to make predictive methods, wireless condition monitoring and computerized maintenance management system (CMMS) software as a service (SaaS) available at an attractive price point. This has become possible primarily because of the IIoT.

A system or plan that unites maintenance reliability capabilities today to enable the facility of the future is ideal and can support the generation, collection and consolidation of data from wireless sensors, handheld tools and existing systems with remote monitoring capabilities through any connected device (e.g., desktop, tablet, or smartphone). Facility managers, engineers and technicians will benefit from integrated data and maintenance management.

Connected Measurements

Having handheld tools and wireless sensors whose data is aggregated in one location is a benefit for plant and maintenance managers. Some wireless sensors that may be beneficial are temperature, electrical, power, thermal and vibration data.

A system that wirelessly connects handheld test tools and sensors to connected devices can provide precise data on asset health to the maintenance manager trying to mitigate failures.

CMMS and Work Order Management

Many enterprise asset management (EAM) and CMMS systems are available. A cloud-based CMMS system allows for flexibility and ease of use for asset management, workflow and work order management, and reporting. Many cloud-based CMMS systems can be up and running almost immediately.

Full Integration Software

Another part of a data management system creates the pathway for integration with and between third party supervisory control and data acquisition (SCADA), enterprise resource planning (ERP) and EAM and CMMS systems, directly connecting maintenance departments to operational metrics. Data integration combined with data management and a mobile control interface gives maintenance and operations staffs the ability to cross-reference process automation information with maintenance activity and inventory records.

Table 1 – Standard Returns on Condition-Based Maintenance	
Return on investment	10x
Reduction in maintenance costs	25% to 30%
Elimination of breakdowns	70% to 75%
Reduction in downtime	35% to 45%
Increase in production	20% to 25%

Source: U.S. Department of Energy Operations & Maintenance Best Practices Guide 2010

The Difference

Adding condition-based/predictive technologies to tier two assets can be as easy as adding a single sensor or an infrared camera with smart software, giving maintenance reliability personnel the ability to begin with a small, incremental step toward predictive methods.

When data is gathered and aggregated electronically, reliability engineers, maintenance managers and other professionals can correlate it from different technologies (e.g., infrared, vibration, power and SCADA) and share the data across the enterprise.

In real time, managers can assess equipment condition and immediately associate that data with work orders, scheduling planned maintenance before unplanned downtime. Technicians benefit from the safety advantages of planned maintenance instead of emergency responses. In addition, safety is at the forefront of using wireless sensors that remove the need for personnel to stand near dangerous equipment or high voltages.

Some cloud-based technology and software can be installed parallel to the existing network, limiting IT involvement. In many cases, maintenance teams can adopt whichever aspects address their needs, all with relative ease, using the staff they have and scaling as desired. Until now, carrying out installations and programs of this kind required costly retrofitting, increased manpower and large investments in IT infrastructure. Today, with incremental application of the technologies and integrating with any system, this can be accomplished with relative ease.

Reference

1. Annunziata, Marco and Evans, Peter C. "Industrial Internet: Pushing the Boundaries of Minds and Machines" report. Fairfield: General Electric, November 2012.

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Broadcasts of professional football league games requires power monitoring to ensure uninterruptible power supply

CASE STUDY

THE CHALLENGE: POWER MONITORING ON THE FIELD IN GREEN BAY

In September 2017, on an unseasonably humid day in Green Bay, Wisconsin, the Filmwerks International, Inc., crew prepped a broadcast stage at Lambeau Field for the professional football league game between Green Bay and Chicago. Filmwerks' core business is providing backup uninterruptible power supply (UPS) for broadcast companies that televise professional sporting and entertainment events, including football, wrestling, golf, mixed martial arts and concerts. For these jobs, the entire Filmwerks team must receive alerts based on customized measurement thresholds that could reveal possible electrical issues.

Filmwerks operates a UPS system with a 500 kilowatt generator to accommodate its clients who broadcast live football games. For the job at Lambeau Field, the company used four, 3540 FC three-phase power monitors with flexible current probes to keep tabs on voltage, amps, frequency and total harmonic distortion.

The power monitor helps professionals monitor power input and output to equipment. Teams can stream vital power data to the Cloud, then access measurement information—displayed in graphs that show baselines and historical data for trending—using a mobile app or desktop interface. From there, technicians and managers can set thresholds for alarms that notify the team when measurements, such as voltage or current, fall outside the accepted range.

THE APPROACH: UPS SYSTEM EVOLUTION

Rick Fadeley, Filmwerks' UPS manager, is charged with alerting clients of notable changes to power before and during events. He also provides comprehensive reports after the referee blows the final whistle. The ability to connect multiple, semifixed power monitors to observe three-phase input and output while being connected to the Cloud gives Filmwerks and its clients confidence in the company's power monitoring efforts.

"Traditionally, in the live broadcast power business, up until a couple of years ago, it was always twin generators for redundancy. So, they weren't even connected to shore power utility at all; they were in isle mode floating these broadcast trucks," explained Fadeley.

Continued on next page

Multiple three-phase power monitors set up to ensure continued flow during a professional football league game

This three-phase power monitor will ensure adequate power during a Thursday night professional football league game

In many ways, Filmwerks is pioneering a greener and more reliable approach by providing UPS technology to clients who cannot risk prolonged outages because substantial advertising dollars are at stake. The company uses a modular design and state-of-the-art battery banks and avoids operating generators and burning diesel fuel, which lowers fuel costs for their clients. The effects are a reduced carbon footprint and minimized excess machine noise. To accomplish this, Filmwerks uses silent UPS systems with battery backup. A big selling point to clients is their knowledge of and ability to remotely monitor power transference.

"Our clients like it and they feel comfortable that everything is going well," Fadeley said. "We also use it for data recording. We get a baseline of what the critical loads are, what to anticipate, and how to connect and load our equipment. It also archives data. We can go back a week or month later and see how that particular show performed and how particular equipment was consuming power. Again, this is all traveling equipment, so every week or so it's in a different location and, at times, with different electrical loads."

IMPLEMENTATION: REAL-TIME DATA

Filmwerks depends on utility power as the primary power supply to broadcast operations, so Fadeley recognized a pressing need to have real-time power data at the team's fingertips. Filmwerks' trailers are equipped with eight custom air conditioning units to sustain a stable room temperature for the battery banks. With access to remote monitoring on his smartphone via the mobile app, Fadeley and his team can be alerted to any power issue that demands immediate attention.

The Filmwerks team begins setup in Green Bay

The thermal imager uses infrared technology to monitor a power cable located in the electrical panel of the Filmwerks' trailer

The Filmwerks team reports power data to each client by individual facility, so it can note any electrical components that were problematic during its past visits.

"Where the data comes in handy is especially in shore power or utility power where you have no control. We're a visitor to this facility. We take what they give us and hope it's good. If it isn't, we like to have data to look at after the event, especially if there are problems. The next time we have to deploy to this stadium, we know what we're dealing with," noted Fadeley.

THE BENEFITS: PEACE OF MIND WITH A THERMAL IMAGER

During the Green Bay setup and broadcast, Filmwerks installed a wireless thermal imaging sensor outside one of its custom-built trailers. Surrounded by the humming of broadcast trailers, team members immediately saw past the initial cool factor of exploring their world through an infrared lens and focused on how the new thermal imaging sensor could improve capacity to capture visual data and, in turn, deliver more comprehensive reports to their clients.

When Dwight Johnson, a generator and UPS technician, interacted with a wireless thermal imaging sensor, he saw immediate value in using it to see if equipment heats up in real time, giving Filmwerks the ability to know what is happening when it happens.

"I want to put it on our house panels, so I know what each phase is doing," Johnson said, highlighting the importance of temperature measurements and identifying hot spots. Remote monitoring from their smartphones is a selling point to their clients, as well as the ability to log data, set temperature alarms and compare thermal images over time. All these benefits empower Filmwerks' technicians to react to issues right away.

The crew set up a wireless thermal imaging sensor to monitor a power cable located in the electrical panel of the company's trailer to take one infrared image every five minutes. Normally, exposure to the sun can impact the thermal sensor's temperature measurement. However, the infrared imager was set up under a switchgear cover to monitor overnight, so the sensor was not exposed to solar heat.

While this monitoring session did not catch any suspicious changes in surface temperature, the Filmwerks crew took comfort in knowing that they would be notified in the event of an issue.

Stephen Satrazemis, who oversees the stage assembly crew for Filmwerks, explained how the app helps the business. "It's very important for us to be able to leave, go to our hotel rooms and sleep at night knowing that, if something does go wrong, we're going to get an alert and we're going to know what happened," he said. "If we don't know, we are constantly thinking about it or have to leave someone behind."

Re reliability engineering

RELIABILITY & INFORMATION

Dr. Dmitry Chaschin

Problems with reliability appeared with the beginning of human activity. However, the ways of solving these problems were different and they were changing with growing complexity of technical systems. The retrospective view shows that the way of solving reliability problems depends on the ratio between the complexity of the system and the ability of people to obtain information about the system and its elements.

For example, it is not difficult these days to find out if a crowbar is reliable enough to do a particular job. The ability of modern modeling packages is sufficient enough to simulate load and stress distribution along the bar. Non-destructive testing methods are sufficient for proving the absence of hidden cracks or voids in the metal structure. Why is this important? It means that if you have an accurate, physical model of the object and sufficient information about the current condition of the object, you can accurately predict what is going to happen to the object.

Many diagnostic methods have been developed and many reliability models have been created, so why does reliability remain a problem?

What Is Reliability and Why Is It a Problem?

Let's start from the question: Which system would you consider reliable:

- The one that would work for 100 hours;
- The one that would work for 1,000 hours;
- The one that would work for 10,000 hours?

Most people familiar with the reliability assessment would choose the one that would work for 10,000 hours because this is the most common understanding of reliability – the ability to work for a longer time.

But, what if it is a torpedo generator? The required operation time for it, before the torpedo hits the target, is several minutes. Will 100 hours be sufficient in this case? It certainly will. The opposite case is a valve for an artificial heart. It should be designed to work for at least 50 years, so even 10,000 hours wouldn't be enough to call this system reliable.

So, all the system choices mentioned are equally unreliable if they failed unexpectedly. Considering the two examples, calling a system reliable would mean it works as long as expected.

Returning to the crowbar example, when you are able to get exhaustive information about the system, its behavior becomes completely predictable and you can call the system reliable.

Looking at reliability from the position of information, the complexity of technical systems were always ahead of the level of knowledge about these systems. In other words, there was always not enough information to determine time to failure accurately. Figure 1 shows the changes in the complexity of technical systems and, according, changes in the approach to reliability problems.

> "...Calling a system reliable would mean it works as long as expected"

As the Figure 1 diagram shows, for primitive systems and very little knowledge about them, there was an intuitive approach to reliability by go/no go tests. The failure could happen any time with the same probability.

The development of basic technical systems, such as a carriage, mill, hut, etc., required some basic knowledge that was mainly gained by experience, with some simple empirical modeling. This was better than nothing, but didn't do much for the improvement of reliability.

The next period contained complex technical systems that presumed complex physical models. Calculations were more accurate, the modeling was more sophisticated and, as a result, reliability could be controlled to a certain degree. But, the knowledge was still not exhaustive, so to achieve higher

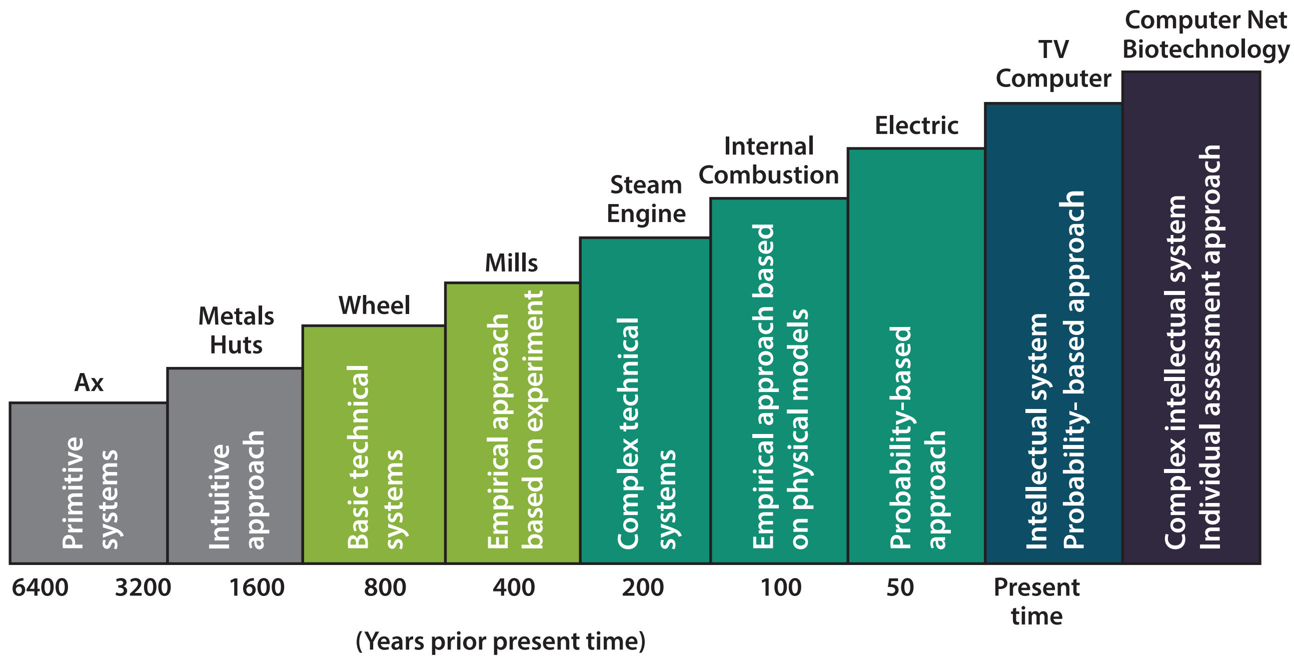


Figure 1: Change of approach to reliability problems with growing complexity of technical systems

reliability, the reserve factors were widely used. This method was acceptable before complex mobile systems were developed.

For example, one can improve the reliability of a shaft simply by increasing its diameter. However, it will increase its weight, too. While you can afford it for some stationary equipment, increased weight is always in contradiction with the restriction of mobile systems, which you are always trying to make lighter. Contradiction initiated the probability-based approach to reliability problems. A probability-based approach is, in fact, a compromise between the level of knowledge one has about a system and the safety factor you can afford.

The first electronic devices, with thousands of similar elements in their circuits, initiated a statistical approach. This gave very accurate results similar to physics, where a chaotic motion of molecules in gas creates determined pressure.

The problem was that the good results achieved in electronics stimulated scientists to apply the same principles to electrical engineering and, in particular, electrical machine manufacturing. But, because electrical machines don't have thousands of similar elements, the theory was applied instead to mass production, where one is dealing with thousands of similar machines.

Although the approach works for manufacturers of high quantities of similar products, it doesn't make the user happy. For example, if a machine fails, the user is not interested in hearing that it was one of 1,000 machines that were manufactured and all other 999 machines are working fine. To make sure every machine is reliable, enough information is required about the strength of the machine, as well as the stress an individual machine will be subject to. All this is considered information.

Reliability and Information

It is relatively easy to show mathematically that there is a direct relation between information and reliability. Take the Weibull distribution in its most applicable form for reliability:

$$P(t) = 1 - e^{-\frac{(t)^b}{a}} \quad \text{(Equation 1)}$$

P(t) = probability of failure; ***a*** = scale parameter; ***b*** = shape parameter; ***t***=time

The mean value [M(χ)] is:

$$M(x) = a \cdot \Gamma\left(1 + \frac{1}{b}\right) \quad \text{(Equation 2)}$$

Γ = gamma function

The standard deviation [σ(χ)] is:

$$\sigma(x) = a \cdot \sqrt{\Gamma\left(1 + \frac{2}{b}\right) - \left[\Gamma\left(1 + \frac{1}{b}\right)\right]^2} \quad \text{(Equation 3)}$$

The per unit deviation is:

$$\frac{\sigma(x)}{M(x)} \quad \text{(Equation 4)}$$

From these equations, you can see that the per unit deviation doesn't depend on the scale parameter. It only depends on the shape parameter.

It is impossible to analytically find the shape parameter for each given per unit variation, however, Figure 2 shows how it looks graphically.

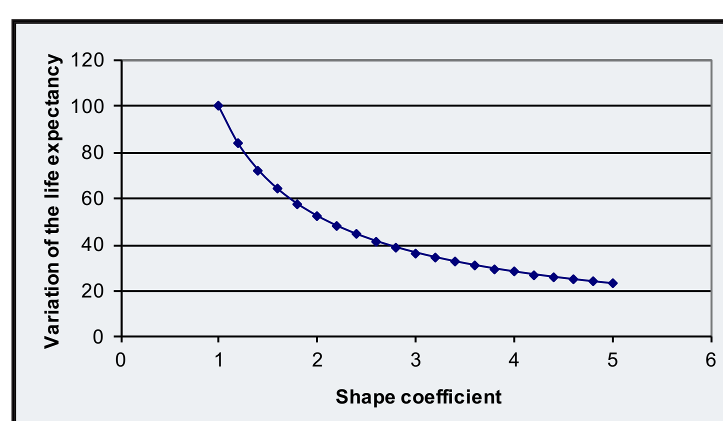


Figure 2: Shape coefficient of Weibull distribution as a function of per unit variation

As Figure 2 shows, the lower the variation, the higher the shape parameter. In technical terms, lower variation can be achieved by measuring and monitoring. And what is measuring and monitoring? Yes, it is gathering information.

Drawing a parallel with time-to-failure, you could say that if you know the strength of the element and the stress this element is subject to, then you will know if the element is going to fail during a given time period. And, the more accurate your information is, the more accurate the answer will be on whether it is going to fail or not.

And what is measuring and monitoring? Yes, it is gathering information.

This means the shape parameter of the Weibull distribution is a measure of information about the process or object. Taking this approach, one can modify the Weibull distribution as:

$$P(t)=1-e^{-\frac{(t)^{b_0+bt}}{a}} \qquad \text{(Equation 5)}$$

t = *time;* b_0 = initial information about the object (measuring); bt = information gathered during the time t (monitoring)

Expressing the failure rate [$\lambda(t)$] from Equation 5, give the following:

$$\lambda(t)=\left\{\frac{b_0}{t}+b\cdot\left[1+\ln\left(\frac{t}{a}\right)\right]\right\}\cdot\left(\frac{t}{a}\right)^{b_0+bt} \qquad \text{(Equation 6)}$$

Now, have a look at the graph of this function, as shown in Figure 3.

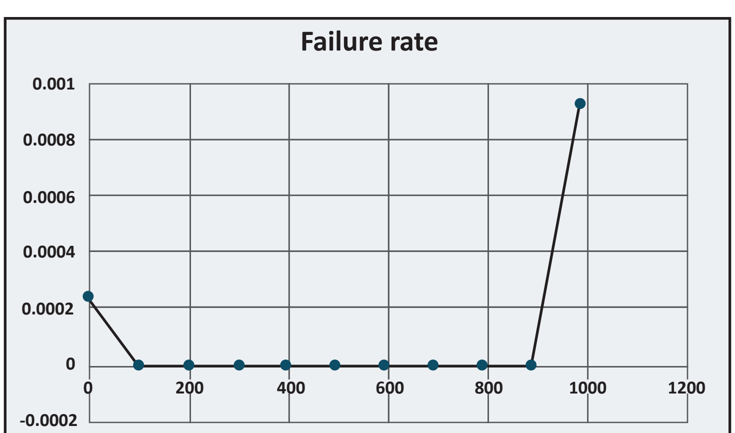


Figure 3: Failure rate curve received from modified Weibull formula

It looks like a classic reliability bathtub curve. Interestingly enough, this shape only can be achieved by a very specific combination of modified Weibull parameters. The curve shape is very sensitive to shape parameter which, as you already know, is representing the amount of information that you have about the object.

Using the Equation 6 with different parameters, you can simulate various scenarios. For example, if $b_0 = 1$ and $b = 0$, you get exponential distribution. Failure rate for this distribution is constant and depends on mean life expectancy. But, what does it mean from an information point of view? It means you only have some initial information. For example, you have a running motor; this is your initial information. You don't know how long the motor was running before, the load, temperature, vibration, etc. As such, the failure can happen at any time and it becomes a Poisson process with a constant failure rate.

Is it possible to control reliability using information? Yes, here is an example.

An induction motor is driving a fan through the pulley and a set of V-belts. The drive end (DE) bearing is a 6305. The other parameters are as follows:

Basic dynamic load rating	C = 22500 N;
Mean value of the dynamic load	P = 1000 N;
Rotation speed	n = 1500 RPM;
Belt tension force	Pb = 400 N; force variation from 100 to 700 N
Magnetic pull force	Pm = 150 N; force variation from 0 to 300 N

All other components (e.g., fan load, contact angle of the bearing, temperature, lubrication characteristics, etc.) are stable.

Assume a Gaussian distribution for the simplicity of the analysis.

1. Variation of the tension force: 700-100 = 600 N
2. Estimation of the standard deviation: 600/6 = 100 N
3. Variation of the magnetic pull: 300-0 = 300 N
4. Estimation of standard deviation: 300/6 = 50 N
5. Resultant variation: $\sqrt{100^2+50^2}$ = 111.8 N
6. Estimated mean life expectancy according to the Lundberg-Palmgren model:
   $L=\frac{10^6}{60n}\cdot\left(\frac{C}{P}\right)^3$ = 10^6/60/1500*(22500/1000)^3 = 12656 h
7. Standard deviation in per load units: 111.8/1000 = 0.1118
8. Sensitivity of the time to failure to the variation of the load: S = 3
9. Deviation of the time to failure because of the load variation: 3*0.1118 = 0.3354
10. Deviation of the time to failure in hours: 12656*0.3354 = 4245 h
11. Normalize value of the Gaussian distribution for 4,000 hours of operation: t = (12656-4000)/4245 = 2.039
12. Value of Φ(t) for the above t (from Gaussian distribution table): 0.472
13. Probability of failure within 4,000 hours: 0.5-0.472 = 0.028

If you monitor the belt tension and keep it at 400 N, the variation of the Pb would be 0. Substituting 0 in the above calculation gives the probability of failure:

P(T) = 0.000003

This example shows that by stabilizing only one parameter, one can increase the reliability of the system by 100 times.

Now that you know you can accurately predict the behavior of an object by having full information about it, the next issue is: do you need this information? The answer brings up another aspect of reliability: maintenance strategy.

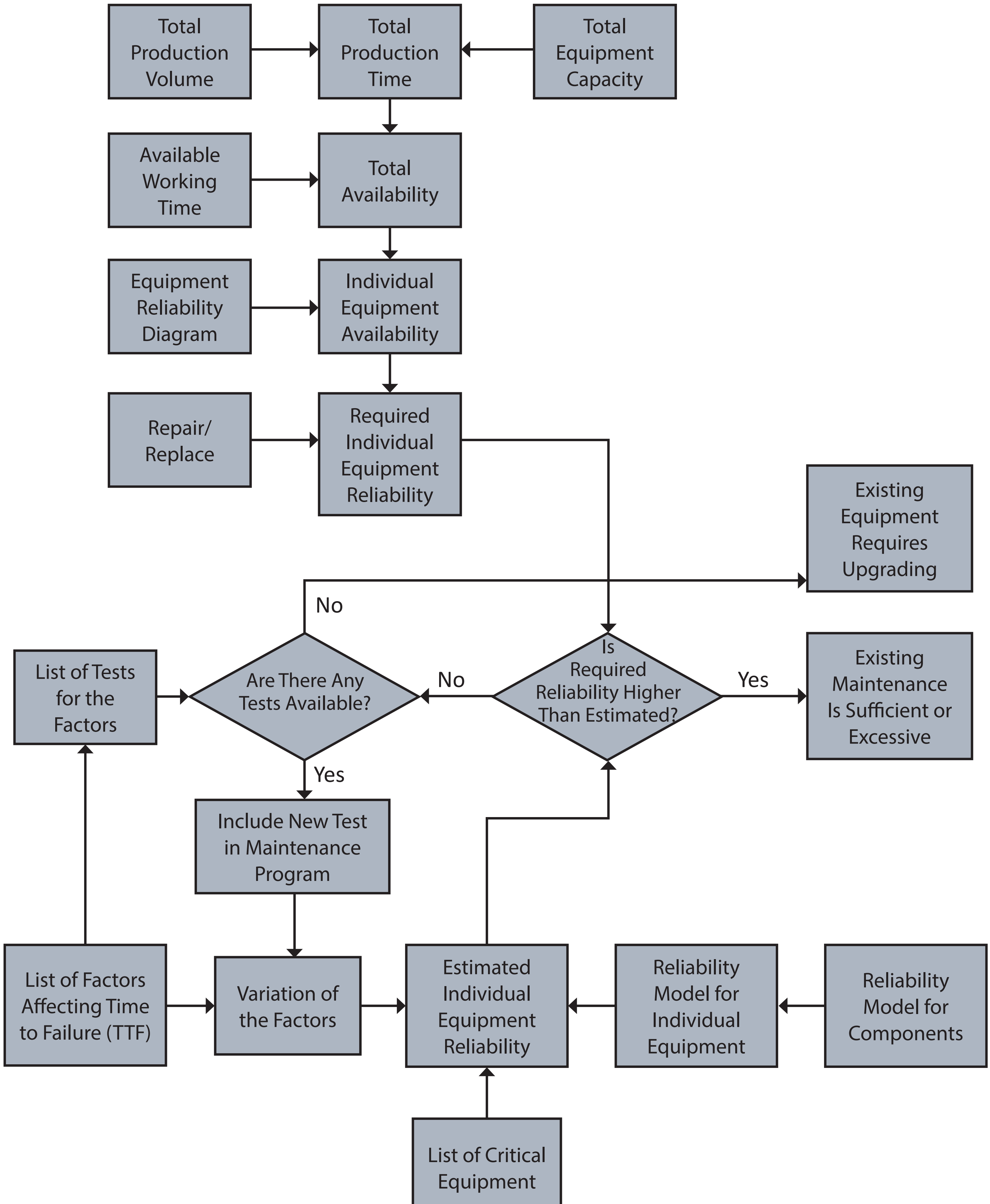


Figure 4: Block diagram of predictive maintenance planning

Reliability and Maintenance Strategies

All maintenance strategies are about one question: Should you stop it or let it run? Two basic strategies are easy and give straight answer to this question. Reactive maintenance says run and face the consequences. Preventive maintenance says stop and absorb the cost. There are no questions about information for these two strategies. The only information preventive maintenance needs is the recommended time between maintenance.

The third real maintenance strategy is predictive. This is where you really need information to make a decision on whether to stop it or keep it running. Other strategies are a combination of predictive, with either root cause analysis (proactive) or failure mode and effects analysis (reliability-centered maintenance).

The latest, asset management, is not a strategy, but rather a facilitator for choosing and implementing the first three.

The most interesting option is definitely the predictive maintenance strategy. This is the one that requires informative answers to the question: should you stop it or let it run? As previously noted, you can achieve high reliability by determining the stress and strength of the machine very accurately. The main challenge is how accurate? You can perform a set of tests while the machine is running. This will give you b or the amount of information. If you know $M(x)$**,** the mean value, then you can determine a and $P(t)$ using Equations #2 and #5. Knowing $P(t)$ gives you an estimation of possible losses as:

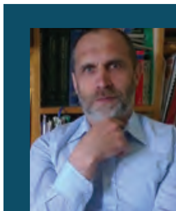
$$L = (T \cdot C + C_r) \cdot P(t) \qquad \text{(Equation 7)}$$

L = possible losses; T = time to repair/replace; C = cost of lost production per hour; C_r = cost of repair/replace

If estimated losses are higher than the cost of diagnostics performed to receive the given value of $P(t)$, then you can increase the number of tests, making sure that they affect the b value.

The diagram in Figure 4 shows a proposed algorithm for working out the number of tests required to achieve a certain level of availability. This diagram and the approach previously described provide the ways to further development in reliability improvement. The obvious challenges are:

- Developing more accurate mathematical models by connecting operational characteristics of equipment and their design parameters to time to failure;
- Improving quality of information provided by condition monitoring;
- Developing new ways for obtaining the information, preferably using online methods;
- Further development of the proposed model that connects the amount of information to reliability of the particular object.



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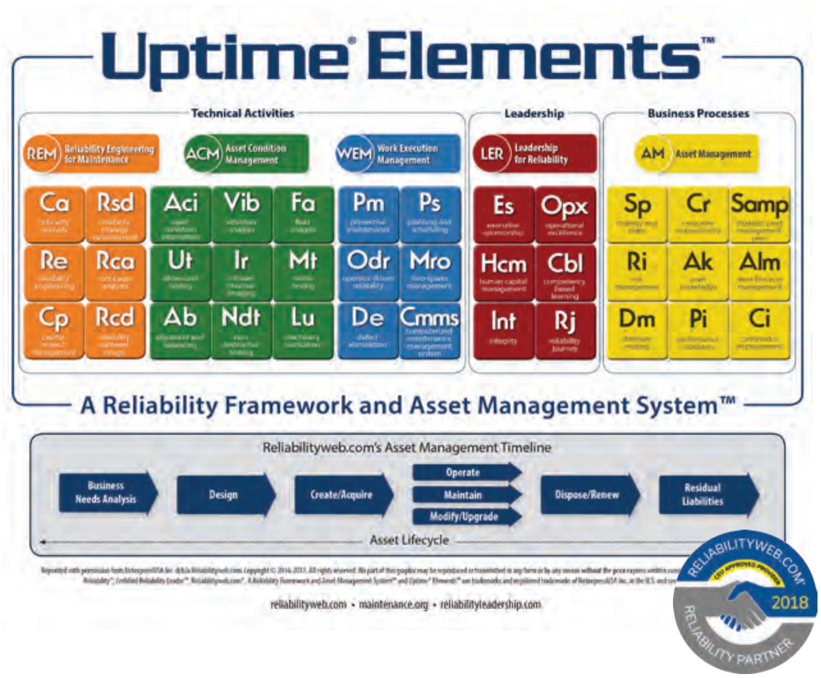

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ASSET PERFORMANCE MANAGEMENT 4.0 AND BEYOND

Alok Pathak

In any asset-intensive industry, businesses are pressured to continually improve asset performance and reliability while minimizing costs and ensuring regulatory compliance for e.g. safety. In this environment, optimizing maintenance is critical.

ADVANCE YOUR MATURITY LEVEL USING A PHASED APPROACH

New technologies, such as the Cloud, big data management, complex systems modeling and advanced analytics and concepts, such as the Industrial Internet of Things (IIoT) and Industry 4.0, offer users the ability to strategically plan, forecast and optimize their maintenance. Leveraging these new technologies enables an evolution beyond traditional reactive maintenance and toward proactive maintenance. This is the future of maintenance, operations and asset management, namely Asset Performance Management (APM) 4.0.

APM 4.0 AND THE MAINTENANCE MATURITY PYRAMID

With APM 4.0, it's important to consider the various levels of maintenance, the value of each approach and where those levels fit into a comprehensive maintenance strategy. The maintenance maturity pyramid helps to visually represent the journey toward more proactive and optimized maintenance execution, all of which should be embedded in a solid asset management system, such as the International Organization for Standardization's ISO55000. Enterprise-wide data management, risk management and mitigation form the foundation for a comprehensive APM strategy.

> "The maintenance maturity pyramid helps to visually represent the journey toward more proactive and optimized maintenance execution"

At the bottom of the maintenance maturity pyramid is the most basic approach, reactive maintenance. Reactive maintenance involves letting an asset run until it fails. This is suitable for noncritical assets that have little to no immediate impact on safety or plant availability and have minimal repair or replacement costs.

The next level of maintenance maturity is preventive maintenance (PM), which is regularly scheduled maintenance implemented in hopes that an asset will not reach the point of failure. The PM strategy prescribes maintenance work to be conducted on a fixed time schedule or based on operational statistics and manufacturer/industry recommendations of good practice. PM can be managed in the enterprise asset management (EAM) program or computerized maintenance management system (CMMS).

Some failure patterns in equipment are not related to aging or usage, but appear to happen stochastically. Hence, condition-based maintenance (CBM) is sometimes recommended. CBM focuses on the physical condition of equipment and how it is operating. It is ideal when measurable parameters are good indicators of impending problems. The condition is typically defined using rule-based logic, where the rule does not change depending on loading, ambient, or operational conditions. If the condition is met, work orders can be automatically generated to help mitigate risk and proactively resolve potential problems.

For more complex and critical assets, a predictive strategy is appropriate. Using predictive maintenance (PdM), organizations are able to move from asking, "Why did that happen?" to "What will happen?" Predictive asset analytics solutions learn an asset's unique operating profile during all loading, ambient and operational process conditions. Existing sensor data is compared to real-time operating data using advanced analytical modeling techniques to determine and alert upon subtle deviations from expected behavior. Once an issue is identified, root cause analysis and fault diagnostics help the user to determine the significance of the problem and the resulting course of action. These early warning notifications enable users to address issues before they become problems that significantly impact operations.

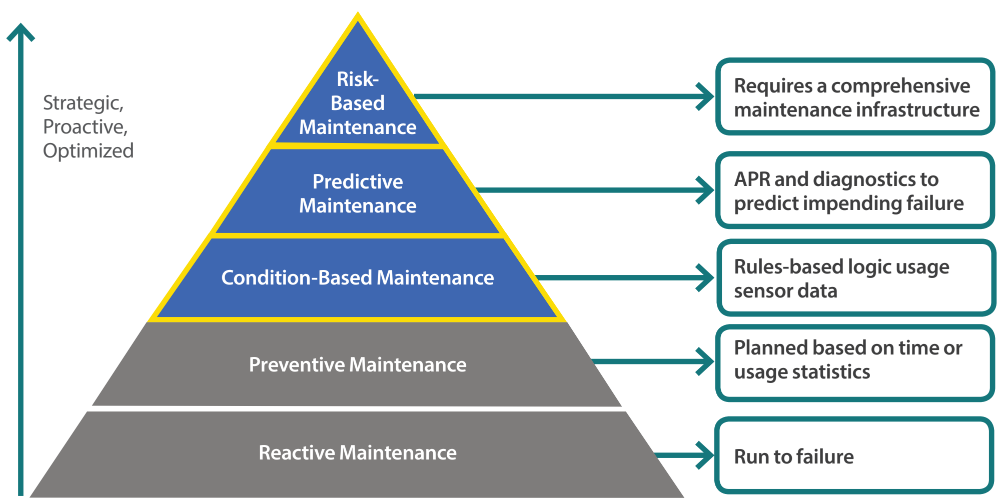

Figure 1: The maintenance maturity pyramid

The implementation of risk-based maintenance involves a comprehensive maintenance strategy that leverages existing data, advanced analytics and simulations, and forecasts to understand the true issues driving asset performance and reliability. By implementing risk-based maintenance, organizations are able to move beyond preventing failure and toward optimizing future performance. In other words, moving from, "What will happen?" to "What should we do?" This moves the asset from being merely a cost center to a major driver of profitability for the business.

RISK-BASED MAINTENANCE BENEFITS

Risk-based maintenance holds numerous benefits for organizations. First, getting the most out of your existing production assets is a key success factor in achieving business objectives. Risk-based solutions allow companies to prioritize asset management by focusing on the assets that need attention. Advanced asset criticality analysis ensures the most important assets receive priority and more rigorous analysis for optimal maintenance. When asset failures occur, root cause analysis enables users to quickly diagnose the cause and take action to eliminate reoccurring incidents. Inventory management quantifies the effect of spare parts to optimize asset management levels.

The second key benefit of risk-based maintenance is strategic. By practicing a future-focused, risk-based asset management strategy, users can perform detailed analysis and simulations to visualize the effects of deploying different asset management strategies and, ultimately, achieve short-term efficiencies and long-term sustainability. In-depth risk analysis provides detailed insight into the real factors driving asset reliability and performance, thus facilitating long-term planning. Extensive simulation capabilities allow for augmented intelligence, enabling users to see the impact of differing asset management approaches and resulting in an aligned strategic approach to operations and asset management.

One particular question that can be considered one of the largest pain points of asset-intensive industries is: "How do we allocate resources efficiently and fairly between competing short- and long-term commercial, social and environmental interests?" Therefore, it is important to consider the role and impact of accurate financial forecasts, as unexpected shifts in capital expenditures (CAPEX) and operating expenses (OPEX) budgets can derail even the most best-laid asset management plans. Advanced risk-based maintenance tools allow users, including those from different silos, to design, simulate, measure and optimize CAPEX and OPEX assessment plans, ensuring asset management plans accurately reflect the likely financial future. Risk-based maintenance technologies can provide quick time to value; a solution with an extensive library of readily available reliability data can speed up deployment time by up to 90 percent.

PROVIDING CLOSED LOOP OPTIMIZATION

A comprehensive enterprise APM solution enables an APM 4.0 approach by ensuring maintenance strategies are deployed in the most efficient and effective manner possible. Enterprise APM solutions manage the collection of data from any number of sources, incorporate advanced analytics technology that combines rules-based logic and machine learning, and can trigger actions in the work order system to manage asset lifecycle and maintenance processes. These solutions help maintenance teams, systems engineers, controllers and many others take advantage of the massive amounts of data available today and use it to answer questions and make real-time decisions to maximize asset reliability and performance.

Using enterprise APM, engineers can identify and predict asset failures early on so personnel can spend less time sifting through raw data and spend more time proactively improving plant performance. Integration with advanced workflows facilitates the continuous improvement process, constantly driving improved operational excellence. An open-ended and hardware agnostic solution enables easy integration with existing systems.

APM 4.0 IN ACTION

Innovative companies are reaping the significant benefits of implementing proactive maintenance strategies today. When a major dairy company implemented risk-based maintenance, the results were a 30 percent spare parts cost reduction and a three percent increase in productivity in the first year. The investment paid for itself sevenfold on a yearly basis and the APM implementation also initiated a systemic cultural shift as the existence of extensive data libraries enabled a company-wide culture of risk awareness, asset responsibility and problem ownership.

In an increasingly competitive market, organizations across multiple industries need to be able to take the bold steps necessary to optimize their maintenance strategies and operations. A rigorous, risk-based maintenance solution that can evaluate how cost, risk and performance should be balanced over time to deliver sustainable outcomes isn't a choice anymore, but a necessity. Implementing APM 4.0 enables the transition to full, risk-based maintenance for improved asset performance, increased asset reliability, reduced risk and, ultimately, maximum return on asset investments.

Alok Pathak *is Director, Global Consulting Head of Asset Management, Mobility and Analytics for AVEVA. Alok is a consulting and business development executive with over 20 years' management experience in asset management fields including, asset performance management, enterprise asset management, industrial mobility and predictive.* *www.software.schneider-electric.com*

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This course teaches both practical and theoretical modeling of rotating systems using journal and rolling element bearings.

Advanced Vibration Analysis - CAT IV

This course is targeted to solving complex vibration problems involving transient and forced vibrations, resonance, isolation and damping, advanced signal processing analysis, and torsional vibration analysis.

Advanced Vibration Control - CAT IV

This course is targeted at solving complex vibration problems involving transient and forced vibrations; resonance, isolation and damping in both structural dynamic and rotor dynamic systems.

Dates & Locations

Introduction To Machinery Vibrations - CAT I

- March 5-8, 2018 Oak Brook, IL
- May 8-11, 2018 New Orleans
- August 7-10, 2018 Indianapolis
- October 2-5, 2018 Orlando, FL
- December 11-14, 2018 San Diego

Basic Machinery Vibration - CAT II

- February 5-9, 2018 Tempe, AZ
- April 9-13, 2018 Knoxville, TN
- June 18-22, 2018 Oak Brook, IL
- July 16-20, 2018 New Orleans
- September 24-28, 2018 San Antonio, TX
- November 5-9, 2018 Indianapolis

Machinery Vibration Analysis - CAT III

- March 19-23, 2018 Oak Brook, IL
- May 7-11, 2018 New Orleans
- August 6-10, 2018 Indianapolis
- October 1-5 Orlando, FL
- December 10-14, 2018 San Diego

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Practical Rotor Dynamics & Modeling - CAT IV

- April 9-13, 2018 Knoxville, TN

Advanced Vibration Analysis - CAT IV

- November 6-9, 2018 Indianapolis

Advanced Vibration Control - CAT IV

- September 25-28, 2018 San Antonio, TX

Fa
fluid
analysis

MANAGING EFFECTIVE FLUID ANALYSIS:

10 STEPS TO REALIZE YOUR RETURN ON INVESTMENT

Henry Neicamp

> "Quality fluid analysis helps reduce repair, rebuild, or replacement costs and cost avoidance for excessive downtime"

Fluid analysis is an incredible tool to ensure your maintenance program sees a significant return on investment for your efforts. Not only is it an informative diagnostic tool, but fluid analysis also can help you increase productivity and boost company profits. Whether you are looking to use it alone or alongside other diagnostic technologies, fluid analysis can help you detect a variety of problems before they become failures.

Learning how to effectively manage your fluid analysis program is necessary if you wish to have a real impact on your return on investment. Quality fluid analysis helps reduce repair, rebuild, or replacement costs and prevents equipment downtime. Whether you are using fluid analysis to make sound maintenance decisions or save money, there are a few steps you can take to better reach your company's objectives.

1. SET ATTAINABLE GOALS

Measure the success of your maintenance program by setting attainable goals. Then, review your current practices and strategies to see if they are helping you reach your goals. If they are not helping, it may be time to re-evaluate your methods.

Try tracking:

- When fluid analysis recommendations result in equipment maintenance;
- How much downtime has decreased and, conversely, how much uptime has increased;
- The amount of money saved by extending drain intervals and reducing consumption of oil.

Don't forget to track your documented accomplishments and share those wins with your team!

2. THE PERFECT TEAM

If someone is taking full responsibility for the implementation of the fluid analysis program, this individual is your program champion. This could be you or a team member you feel would be successful at managing this particular project. Other roles to determine include those who will be pulling samples and managing the data.

Samplers are typically the personnel responsible for fluid and filter changes and other routine maintenance. They should be trained on the installation and use of the sampling devices and methods you've chosen to use. They should also know how to properly document sample information sent to the laboratory.

Data managers need access to a computer and the Internet, and should have solid computer skills and an understanding of databases. They also should be given extensive training on the fluid analysis data management software programs you intend to use.

3. WHAT TO TEST

Most fluid analysis program goals are centered on saving money. Those savings can be realized through reduced downtime, increased production, less fluid purchased, less equipment replacement, or less repairs and/or rebuilds. However, what to test depends on your objectives.

For monitoring the condition of the unit and the fluid, advanced testing for wear, lubricant properties and contamination are used. The base number, acid number and oxidation/nitration testing are vital to extended oil drain intervals. Particulate analysis monitors the size, count and distribution of ferrous and nonferrous wear particles using ISO particle count, particle quantifier (PQ), or analytical ferrography and micropatch testing.

4. SAMPLING FREQUENCIES

Although an equipment manufacturer's recommendations provide a good starting point for developing preventive maintenance practices, sampling intervals can easily vary. The degree of criticality to production is the most important factor in determining which units or components you will test and how often.

Environmental factors, such as elevated temperatures, dirty operating conditions, short trips with heavy loads and excessive idle times, are also important sampling considerations. Dirt, system debris, water and light fuels tend to separate from the oil when system temperatures cool. In order to collect a representative sample, they should be collected while the system is operating or immediately after shutdown.

Timing is also critical. Trend analysis works best when sampling intervals are consistent and samples are shipped for analysis immediately. Maintenance personnel responsible for sampling should be well trained on the appropriate sampling point(s), the designated method for pulling samples and the recommended sampling frequency for each specific component.

5. KNOW YOUR EQUIPMENT

Accurate, thorough and complete equipment and fluid information improves in-depth analysis and increases the value of a data analyst's comments and recommendations. Obtain the most current, accurate equipment identification information for your laboratory. This includes:

- Make;
- Model;
- Application;
- Filter types with micron ratings;
- Sump capacity;
- Hours/miles on the unit;
- Hours/miles on the fluid;
- If fluid has been changed or topped off.

Make sure to consult every resource available to you, such as procurement records, inventory databases and original equipment manufacturer (OEM) service manuals. Once the laboratory has imported the information, request a copy to verify its accuracy and make sure to communicate any needed changes promptly.

6. TAKE AN ACTIVE ROLE IN MINIMIZING SAMPLE TURNAROUND TIME

Don't let the value of fluid analysis results and recommendations be diminished by unnecessarily slowing down how the sample is processed. Samples can be received more quickly by the laboratory when the sample label information is legible and accurate, but the fastest processing occurs when samples are submitted online.

To make sure your sample is processed efficiently:

- Clearly mark special instructions on the label and close all lids tightly.
- Use a mail service that has online tracking to send samples to your laboratory.
- Receive your results electronically.

7. REVIEW YOUR REPORTS AND TAKE ACTION

When reviewing your most severe reports, consider all other available diagnostic information, such as vibration analysis, thermography, ultrasound, in-line sensors, or any other information you may have at your disposal. Make a decision either to act on the analyst's recommendations or order more testing. If the data analyst recommends resampling, immediately sample again or at half the normal interval to verify results. If not, monitor the unit closely and sample again at the normal interval.

8. MANAGE THE DATA

Raw data can be overwhelming and does not give clear recommendations on what to do next. Use the tools available to sort old and new data into reports to identify trends and correlations. That data then can be compared to industry standards or normal ranges to provide useful information, such

> "Have a system in place that allows you to take action"

as when to perform preventive maintenance and when to wait. Many data management systems can run reports automatically, providing easy to understand recommendations without a large time investment.

9. CONTINUALLY MONITOR FLUID ANALYSIS COMMUNICATION CHANNELS

Have a system in place that allows you to take action. Failing to do so may not only lead to unnecessary downtime and/or failure, but drastically reduce the value of your fluid analysis dollar. The effectiveness of fluid analysis is best measured when the maintenance performed can be correlated to fluid analysis recommendations. Your laboratory should be able to document your feedback on maintenance or diagnostics performed and use it to improve its flagging and severity protocols.

10. CHOOSE THE RIGHT LABORATORY

Expect quality results from your fluid analysis laboratory. Quality data should be repeatable, reproducible and have validated degrees of uncertainty available to the user. A2LA's accreditation of a laboratory's compliance with ISO17025 – now the international standard for testing and calibration laboratories – is the highest level of quality attainable by a testing laboratory. Dedicated to formally recognizing competent testing and calibration laboratories, the independent and nonprofit A2LA is the most stringent, internationally-recognized accreditation body in the industry.

When deciding if a fluid analysis laboratory is right for you, consider the following:

- Can it meet all the requirements of your program?
- Can it perform the testing you need in an appropriate amount of time?
- How does the laboratory ensure consistency from location to location?
- Will you always be able to speak with an analyst?
- Does the laboratory provide training?

Although price is always a factor, quality results, good turnaround time and good communication are essential to both a good relationship with your laboratory and maximizing your return on investment for your fluid analysis program. Any condition-based monitoring program must be viewed as a service that saves you money, **not a cost**. If substantial cost savings cannot be attributed to fluid analysis, serious changes to the current program should be considered. If it is not saving you money, you are not doing it right. Successful fluid analysis programs do pay off!

Henry Neicamp *is a Technical Business Consultant for POLARIS Laboratories®. Henry brings more than 30 years of experience in sales and fluid analysis, lubricants and field services. He is an active member of STLE (Society of Tribologists and Lubrication Engineers) and is a certified lubrication specialist and a certified oil monitoring analyst, Level 1, through the STLE. www.polarislabs.com*

Pm
preventive
maintenance

THE IMPORTANCE OF PREVENTIVE MAINTENANCE

Jason Spivey

Picture this: Like many Americans, you own a motor vehicle of some sort. That vehicle gets you from Point A to Point B, day in and day out. But, if you're like most vehicle owners, you don't consider basic routine maintenance, even on something you rely on the most. It is more of a break/fix relationship. Unfortunately, this same type of relationship is not uncommon in today's data center industry. Various types of equipment are running 24 hours a day, 365 days a year, which comes out to 8,760 hours in a year. Data centers cannot afford any of their equipment to fail. Therefore, preventive maintenance (PM) is a must.

Preventive maintenance *is* routine maintenance, performed to ensure asset reliability and eliminate any equipment failures and/or downtime that may occur. Preventive maintenance should be viewed as a proactive approach that establishes scheduled inspections of assets to verify dependability, as well as prolongs asset longevity.

Today, data center operators spend mind-boggling amounts of money to get the newest data hall complete for an incoming tenant, but they may not give much thought on the front end to having a PM plan in place when the original equipment manufacturer's (OEM's) warranty runs out. Granted, most issues with new equipment are found during start-up and commissioning, but what happens three to five years down the road when an incident occurs?

Reactive maintenance is a common practice for some facilities. Being the opposite of preventive maintenance, reactive maintenance is essentially waiting for an incident to occur. This practice may seem like a cost saving strategy, but when unplanned downtime occurs, you spend more time fixing the issue than if you had a PM plan in place. This delayed maintenance could result in negative publicity for your facility and, in turn, compromise your customers' trust. A PM program is meant to alleviate these unforeseen outages and help save facilities time and money.

> “Data centers cannot afford any of their equipment to fail”

Equipment that is not regularly serviced can create a hazardous and unsafe workplace environment. Having a PM program in place helps ensure the safety of employees in the facility, eliminating injuries and accidents.

More importantly, factory-trained technicians, in collaboration with data center facility managers, should perform the PMs to ensure service level agreements (SLAs) are not breached. For example, if an SLA requires the colocation provider to perform routine maintenance annually to uphold the agreement and ensure the customer's data isn't compromised, this requirement must be met.

Another aspect to consider as part of any good PM program is an equipment lifecycle plan, where IT managers need to:

- Rotate out equipment for routine overhauls;
- Replace devices before they fail;
- Modify or update devices;
- Set lifecycle dates and replace when necessary.

Along with a good PM plan, it is also important to have a power protection plan (PPP) in place to eliminate or minimize downtime in a data

> “A PM program is meant to alleviate these unforeseen outages and help save facilities time and money”

Figure 2: Field service technician confirming calibration and functionality on a static transfer switch during a routine PM visit

Figure 1: Field service technician verifies static transfer switch voltages and performs visual inspection during a routine PM visit

center. Every PPP needs to include the following process:

- Comprehensive preventive maintenance visit annually by a factory-trained customer service engineer;
- Execution vis-a-vis a thorough visual inspection of all parts (e.g., bulbs, displays, missing hardware, cleanliness), with corrections made as needed;
- Verification and calibration of all monitoring components;
- Verification of proper operation and condition of the system;
- System check for proper load balance, kVA usage and building alarm status;
- Complete reporting on all services rendered;
- Infrared scanning of internal connections to seek out hot spots that lead to component deterioration and disaster before they occur;
- Four hour response time during downtime;
- 24x7 access to telephone technical assistance from OEMs;
- Costs for parts and labor required to correct any problems or keeping the system in good operating condition;
- Guaranteed parts availability;
- On-site spare parts kit.

Needless to say, during downtime, on-site factory spare parts are essential for reducing the mean time to repair (MTTR). While factory technicians may be able to respond quickly, not having parts on-site means a longer wait period for them to be shipped from the OEM.

Another approach to ensuring maximum uptime is to make sure your facility’s team is factory trained by the OEM. This eliminates nuisance service calls to the OEM, which often causes customer anxiety.

With the vast expansion of the Internet of Things (IoT) and semiautonomous cars, reliability of data centers and cloud storage is a necessity, not just a nice to have feature. Preventive maintenance should always play a major role in data center operations. But, without proper foresight and a well-thought-out plan for maintenance, data center managers are inadvertently steering the business toward having more problems than it needs to have.

Mitigating risk is possible by charting a preventive maintenance course and preparing for the possible risk factors. In this manner, if a power outage does occur, the impact is reduced and the organization does not become the next data center failure headline.

Jason Spivey *is the Global Product Manager of Service for Power Distribution, Inc. (PDI), located in Richmond, Virginia. Jason has over 10 years of industrial experience, with a career focus on data center service.* *www.pdicorp.com*

Opx operational excellence

CHALLENGING THE STATUS QUO

Mark Rigdon

Driving operational excellence is one key goal for every asset industry site. Manufacturers want to meet customer expectations and have sustainable improvements in the performance of their assets. In order for companies to achieve optimum performance, they create vision statements and mission statements supported by goals and objectives. To reach these goals, companies must challenge the status quo, which begins with clearly redefining roles and responsibilities for all levels of the organization. Everyone must understand their role in order for the whole team to deliver on the promises being made. Only by setting referenced expectations and describing the best practice for each position can a site reach its full potential. This article demonstrates how an organization can lay this foundation of expectations to improve upon the currently confusing conditions in which people understand their responsibilities.

> *If you want to go fast, go alone; if you want to go far,* ***go together.***
> *~ African proverb*

A Real-Life Example

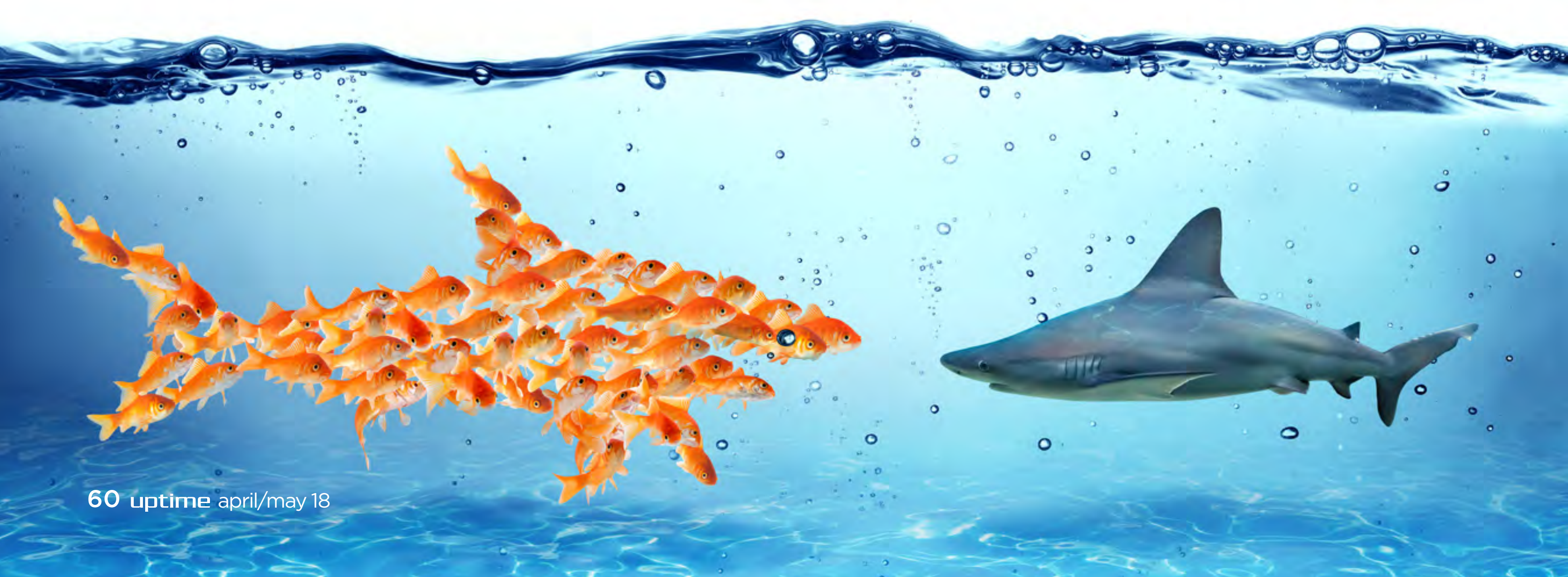
To understand what it means to challenge the status quo, consider an example taken from the offshore gas production industry for the task of managing the unconstrained potential of a gas producing well. There are four groups of site employees who all believe their position plays a role in defining the absolute best possibilities of the well: the geologists, the performance engineers, operations and sales. What was the impact or consequence of these misaligned responsibilities? Each group was unsure as to where one department's responsibilities ended and another began. To challenge and improve this chaotic norm, the organization had to clearly redefine these four positions.

This redefinition process informed every employee of their intended role, how their tasks fit together with their coworkers and what the expectations were. To accomplish this, the site executed several workshops with key stakeholders to create and agree upon a responsibility assignment matrix (RACI). This chart included all activities involved in operating and enhancing the well's performance for its entire lifecycle. The RACI provided a shared vision and set of expectations for everyone in order to ensure the site could be managed more efficiently without any unnecessary and costly confusion.

RACI Details

No one department should stand out or stand alone in the process, even though this is often the case. All departments must work in unison to achieve higher levels of success. This is where the RACI comes into the picture.

Geologists are the only employees who will appropriately determine a well's unconstrained potential. It is the role of the site geologist to review all the data related to existing and new wells and define the potential for produc-



tion within them. This task does not consider any operating constraints that may exist, but rather focuses on production possibilities. This foresight geologists provide is not likely to be successful if it does not include the knowledge of potential pitfalls projected by the performance engineers.

Performance Engineers define the constraints for reaching the prospects detailed by the geologists. Once the performance engineers have defined the limitations, they are responsible for overcoming these restrictions. This group of employees proposes and designs development projects and provides detailed instructions for the operations department, which will implement the plans.

Operations personnel are responsible for the actual production based on the plans of the engineers and the promises of the geologists. Once the instructions are detailed by the performance engineers, the operations department executes the gas extraction. This department identifies and controls any operational issues that may arise and provides qualified, quantified data feedback to the performance engineers. The performance engineers use this data to constantly strengthen the foundation on which they build their plans for current and future projects.

Sales is in charge of offering customers a realistic expectation of what will be produced on a quarterly, monthly, weekly and daily basis. Sales personnel utilize all the information provided from each entity to make an informed decision on consumer commitments. They are also accountable for maximizing profitability by reducing the penalties for underproducing and revenue loss for overproducing.

Approach

Once the key stakeholders have agreed to all the details of the RACI, the process of communicating the new expectations takes place. Trial and error methods have proved that the best way to do this is through a structured workshop. In the case of the offshore gas production facility, the entire organization understood and recognized the changes, thanks to a series of explanatory workshops. Each workshop included geologists, performance engineers, operations and sales personal. In fact, personnel from all the departments within the organization attended the meetings, even if they were not directly affected by the content.

> "Only by setting referenced expectations and describing the best practice for each position can a site reach its full potential"

During the workshop, participants are encouraged to use real-life examples to challenge the revised roles and responsibilities. This gives them the opportunity to raise any concerns and even prompts some minor revisions to the RACI. However, the majority of changes are agreed upon by the entire organization. Thanks to these gatherings, the newly defined roles and responsibilities are executed fully and much more quickly than originally anticipated. With the help of a facilitator to lead the interactive workshops, the site was able to firmly communicate and establish the redefined roles and responsibilities.

By utilizing a workshop approach, not only were the roles and responsibilities clarified, but each person participating in the workshop understood the "why" behind the assigned expectations. This challenges the status quo on a number of levels, not only by allowing all employees to know what is going on, but to make all employees feel significant to the process.

After this implementation process, the site had to develop a way to make sure everyone stayed in their lane for future well development and to track the project's success. A method for managing compliance to the revised roles and responsibilities was developed to ensure the organization continued to follow the new plans. The site implemented a series of follow-up meetings and designed key performance indicators (KPIs) to ensure the revised process was followed. As soon as any divergence from the new roles and responsibilities occurred, the issues were quickly acknowledged and addressed.

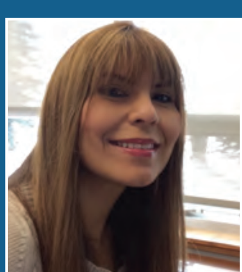
Benefits

Prior to revising the site employees' roles, responsibilities and expectations, employees were only following what they personally believed would be best for the organization and often felt confused and unappreciated when mistakes and miscommunications occurred. The lack of clarity and alignment led to decreased profits because production targets were set lower than actual possibilities. By challenging the existing conditions, this organization was able to increase profits by three percent and increase the standard of work produced by all employees.

SO, HOW CAN YOU CHALLENGE THE STATUS QUO?

***Mark Rigdon** is a manager at T.A. Cook Consultants. With over 17 years of consulting experience, and having worked on projects across a range of different industries, Mark is currently dedicated to the asset intensive refining and petrochemicals industries. He has provided leadership on client projects focused on turnaround excellence, maintenance work order/process improvements and OEE.* www.tacook.com/en

Q&A



Johanna Valera

Johanna Valera, CRL, is a Senior Reliability Specialist with over 12 years of experience in the oil and gas industry, power generation and utilities, and executing and improving asset performance management and reliability programs, including operational performance and reliability analysis, condition monitoring, risk management, continuous improvement, problem-solving, maintenance management, root cause analysis (RCA) and incident investigations, and project management.

Johanna currently works for Inter Pipeline, Ltd. Inter Pipeline is a major petroleum transportation, storage and natural gas liquids processing business based in Calgary, Alberta, Canada. Uptime magazine recently had the opportunity to speak with Johanna about her career, the role of diversity and her position at Inter Pipeline.

Q: How did you get started in this career?

I love challenges. I am always looking to challenge myself somehow, and all this started when I decided to become a mechanical engineer.

Q: Women in Reliability and Asset Management (WIRAM) is committed to increasing diversity in teams to advance reliability and asset management. Why do you feel this is important and how does it add value?

Several social groups, such as women, have been subject to labor discrimination for many years throughout history. We have found many closed doors in society, including jobs. Promoting gender and background diversity in the workplace allows us to evolve into a more inclusive, better informed and more educated society.

I work with a team at Inter Pipeline that is not only culturally diverse and brings different perspectives, but we all come from different work experiences. All of these reasons are why we have a successful and results-oriented team. Every day there are opportunities for learning something new.

Q: What are some examples of how you have successfully promoted diversity?

Since the beginning of my career, I have been working in a male-dominated world, which has generated many professional challenges for me, but it has allowed me to successfully promote diversity by advancing women's equality in the workplace. As part of work teams, I have brought diversity of thought to the table. Successful work teams need to have different brains in the room.

At Inter Pipeline, we have a great mix of ages, cultures and genders that adds to our corporate culture and ultimately makes us successful.

Q: What are some of the challenges faced in advancing diversity in reliability and asset management?

To set the path for more women to be confident about their potential to choose a career in maintenance reliability. To achieve gender parity does not happen overnight.

Q: What suggestions do you have for anyone wanting to support diversity in reliability and asset management?

If you have people from a range of backgrounds, it helps build a robust team and then, ideally, everybody learns from each other. That sums up Inter Pipeline really well. Our diversity is definitely a strength; everyone is willing to share a different perspective.

Q: Who has inspired you as a leader? Is there a quote from that individual that has left a positive influence on you?

There was a person in my life that always inspired me and supported me to be a leader. That person always said to me: "You are a leader, you can do big things!" I am also a fan of Margaret Thatcher and I always remember and inspire myself with her quote: "Defeat? I do not recognize the meaning of the word."

Q: What advice can you share with young women who are interested in a career related to reliability and asset management?

Don't be afraid to do it. It's not easy, but it's a great journey. We need more women in this journey to build a more inclusive world and a better society.

Q: Are there any books you would recommend? If so, what are they?

I just finished reading *10 Rights of Asset Management* by Ramesh Gulati and Terrence O'Hanlon. I totally recommend this book for those who are on the asset management journey.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