What is prescriptive maintenance?

And when will you need it?
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Don’t just predict problems – prescribe a solution. That’s the premise behind the concept of prescriptive maintenance, which works hand-in-hand with prescriptive analytics. Odds are you’ll be hearing these new buzzwords a lot more often in the coming months and years. But what is it really, how does it work, and what can it achieve that other models can’t deliver?

First, to better differentiate the words predictive and prescriptive, the word “prescriptive” will be used interchangeably with “Rx” in places.

Rx maintenance is unique in that instead of just predicting impending failure like predictive maintenance (PdM) does, it strives to produce outcome-focused recommendations for operations and maintenance from the Rx analytics. Though still in its infancy, many thought leaders are entertaining its potential to become the next level of reliability and maintenance best practice.

**ANALYSTS DEFINE RX STRATEGIES**

One of the earlier voices on prescriptive maintenance was Dan Miklovic, principal analyst at LNS Research (www.lnsresearch.com). “No longer will you need an ensemble of experts to tell you how and when to maintain your assets, as the assets themselves will tell you what they need if they are unable to fix themselves,” said Miklovic in his May 17, 2016, blog...
post: What Comes After Predictive Maintenance? He suggested the acronym RxM at that time, and he continues to research the topic.

Better and more data, coupled with Big Data tools that can interpret things like repair manual contents, are the key to unlocking the concept of RxM, he says today (see Figure 1). It starts with prescriptive analytics, which not only tells you that a problem is likely, but it gives you multiple response scenarios to choose from.

“Let’s say a piece of equipment is showing increasing bearing temperature. Predictive analytics looks at the temperature profile and tells you it is likely to fail in X amount of time. On the other hand, prescriptive analytics tells you that if you slow the equipment down by Y%, the time to failure can be doubled, putting you within the already scheduled maintenance window and revealing whether you can still meet planned production requirements,” explains Miklovic.

Another early follower of this trend is Ralph Rio, vice president of enterprise software at ARC Advisory Group (www.arcweb.com).

“From my experience with clients from both the user and supplier side, the dominant application right now is PdM. Prescriptive maintenance is beyond that; it’s new thought leadership. But, the goals of PdM and prescriptive maintenance are similar - to reduce unplanned downtime, which causes lost revenues, materials, and labor,” he says.

To help clients better differentiate the newer approaches from conventional maintenance strategies, Rio developed the Asset
Performance Management Maturity Model (see Figure 2). The upper tiers of maintenance maturity – predictive and prescriptive maintenance – are both multivariate approaches. The current in a pump’s motor drive, the fluid going into the pump, its temperature, and the pressure going in and out can all be combined to better assess the health of the pump and motor, so you get longer advance warning of a failure and can make changes during a planned shutdown, he explains. The Industrial Internet of Things (IIoT) provides the data, and analytics generate the alerts.

Prescriptive maintenance adds the ability to give advice to the technician on what to do and how to do the repair by taking advantage of artificial intelligence (AI) and machine learning. The math algorithms are more detailed and there is some intelligence added to give the technician some direction.

The three lower tiers of Rio’s model include single-variable condition-based maintenance, which provides less advance notice of failure; time- or cycle-based preventive maintenance, which is inefficient compared to higher models; and reactive maintenance, which occurs after failure. There is still a place for each of these approaches for certain assets that are not critical to operations or safety.

Peter Reynolds, contributing analyst at ARC Advisory Group, notes that organizations that shift critical assets to prescriptive approaches are seeing significant improvements in maintenance costs, service costs, plant availability, and efficiency of workers.

The unique abilities of analytics platforms make them capable of ingesting multiple data sources and storing, processing, contextualizing, and visualizing the predictions, he says. Machine learning is integral to the way data is processed that allows algorithms to find looming failures (see Figure 3).

“Machine learning detection occurs by using automated collection of historical multivariate data and analysis with equipment-specific algorithms. Pattern identification points to an explicit diagnosis of root cause and indicates a precise action to change an outcome. Prescriptive advice would include

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**Figure 2. Asset Performance Management Maturity Model with IIoT**
Source: ARC Advisory Group
altering the process operation to avoid a future failure of the asset,” explains Reynolds.

Common drivers of prescriptive approaches Several key business drivers are spurring interest in Rx strategies and driving solution development.

• Automation: As more automation is used in manufacturing, the speed of response required in dealing with maintenance issues is going to get shorter, says LNS Research’s Miklovic.

• Economics: Decisions as to what is the best option from an economic standpoint are getting more complex. “It just isn’t enough to know what can fail or when it might fail. It requires having enough information to understand the options for maintenance as well as the financial implications of each option,” explains Miklovic.

• Workforce changes: Older workers are retiring and newer, younger workers expect smart assistive tools to help them do their job. Miklovic observes that the value in Google directions is they give you options and predict times based on current conditions. He believes maintenance activities should be the same, for instance to service a piece of equipment with an overheating bearing you can either (a) take 20 minutes and grease it and the repair will probably last two days, or (b) replace the bearing, which will take three hours but last for two years.

Figure 3. Machine learning is integral to the way data is processed that allows algorithms to find looming failures.
• Operating conditions: Assets not only fail by their own means, but also by the manner in which they are operated, says ARC Advisory Group’s Reynolds. For example, a pump manufacturer will recommend specific operating design conditions such as discharge pressure and temperature, but there is a lot of variability in process operating conditions and also in the composition of the fluids. Prescriptive analytics can consider these conditions and make recommendations accordingly.

• Asset performance: Reynolds believes a higher level of sophistication is required in the way asset and process data are organized. “The traditional plant historian and analysis tools have not been adequate for ensuring asset performance. IIoT and analytics platforms are unique in their ability to ingest years of operational data and massive quantities of unconventional data scattered through different systems of record,” he explains.

Early adopters are assessing the value. Elevator OEM and maintenance service provider thyssenkrupp Elevator favors cutting-edge maintenance strategies. Dr. Rory Smith, director of strategic development, Americas, at thyssenkrupp Elevator (www.thyssenkruppelevator.com), says at its core, prescriptive maintenance allows thyssenkrupp Elevator to focus on servicing elevators in the most efficient ways possible to increase uptime. Machine learning allows the use of data from its vast network

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Prescriptive recommendations from Intel’s Bunzel

a. Begin with the end in mind. Start your trials for IIoT, analytics, and machine learning on a small scale where the measurable impacts have the potential to make a difference for your company.

b. Expect failures along the way, and treat each failed experiment as a theory tested and ruled out. These are indeed small successes.

c. Begin by connecting unconnected equipment. Learn from your interactions with the hardware and software component suppliers.

d. Harvest expertise in your own enterprise. Machine-based learning algorithms depend on human knowledge of key processes in manufacturing. These experts are nearing retirement so bring them on the development team early.

e. Test results with end users early to prevent wasted cycles and improve the results.

f. Show off! Build internal communications plans into your project. The IIoT is part of a Virtuous Cycle of Growth – you’ll want continued support.
of elevators to better identify the service tasks most critical to maintaining a safe and reliable elevator.

“thyssenkrupp Elevator has a team of data scientists and domain experts working in unison to develop predictive models,” says Smith. “These models inform our service program, and paired with our network of skilled service technicians, are ultimately responsible for maintaining elevator uptime for our customers.”

The company’s predictive model continues to evolve thanks to machine learning, but it can already predict five days in advance when an elevator will shut down due to a door problem (see Figure 4). This early warning has proved to be highly accurate with no false positives, and therefore invaluable to thyssenkrupp customers.

“With MAX, our PdM IoT solution, our computing power takes this a step further,” adds Smith. “Even before a service technician arrives on site, the expert system we refer to as ‘The Coach’ advises the technician on the four most likely causes of the problem, based on the data, with 90 percent accuracy. This means thyssenkrupp technicians can fix an issue on the first visit more than 90 percent of the time. The industry average for initial diagnosing is about half that,” he explains.

Figure 4. Machine learning allows algorithms to find looming failures in assets like this elevator motor.
Intel is at the forefront of research, development, and deployment of advanced technology for manufacturing, including frameworks to support prescriptive analytics (see Figure 5). Often, proofs of concepts are deployed in Intel Fabs (fabrication plants) to answer the demands of a manufacturing environment that requires precision manufacturing to atomic-level specifications in a completely sanitary environment.

“Intel made the journey to PdM decades ago. There are many examples of solutions we’ve developed with our partners being deployed in both our facilities and in our partners’ customer sites,” explains Mary Bunzel, general manager, manufacturing and industrial solutions at Intel (www.intel.com). “Evolving to prescriptive maintenance, where probable cause and automated maintenance are implemented, is a necessary next step in the Industrie 4.0 journey in order to keep up with the demands of fast-paced change in our market.

A specific example of one such case study is a project recently implemented in Intel’s Ireland Fab plant, which addressed conservation of energy used to cool water for the production facilities. “By integrating sensed data from the outside ambient temperatures for areas the pipelines travel through, with the water temperature, the amount of energy used to cool the water has been reduced by as much as 40%,” says Bunzel. Energy conservation is a key imperative for Intel so the return on investment (ROI) is far greater than just monetary savings alone, she adds.
SparkCognition is helping a wind turbine operator incorporate prescriptive analytics into its maintenance routine. “Because of the thin margins facing the wind industry today, turbines must be running at maximum capacity to get a full payback, and any amount of downtime cuts significantly into profits,” says Stuart Gillen, a senior director at SparkCognition (www.sparkcognition.com).

SparkCognition and its customers leverage data that is already available, yet in many cases unused. Utilizing AI techniques, the system is able to find patterns in large data sets that point to eventual failure. These identifying patterns can then be tracked and/or monitored and provide early warning evidence to subject matter experts, operators, management, etc., for work planning. These systems are also able to incorporate unstructured data like work orders, parts databases, and operational and technical manuals to provide a true prescriptive view. “Not only is the user now able to understand something is going to fail, but they are provided with evidence about how to address the problem. This provides dramatic savings to operators,” explains Gillen.

For example, for a single component on a single wind turbine, SparkCognition conservatively estimates the following annual cost savings from AI:

- Downtime savings: $1,000
- O&M savings: $2,500
- Total savings: $3,500

The wind turbine operator’s savings are expected to rise significantly from continued
machine learning, and also by identifying more components for monitoring over time (see Figure 6).

**RECOMMENDATIONS TO ASSET USERS AND SUPPLIERS**

The market will determine whether Rx maintenance will become the ultimate best practice for reliability and maintenance, but those following the model closely are encouraging its adoption.

“Start now,” says Gillen. “What we are seeing across many industries is with very few sensors, which are typically already installed, information can be discovered leading to dramatic cost savings.”

RxM isn’t needed for every asset. It should be used where it makes sense because the asset is critical to production (volume, quality, etc.) or to safety, suggests LNS Research’s Miklovic.

ARC Advisory Group’s Rio recommends using PdM on all of your critical assets since its ROI has already been proven, and it has become less expensive and more sustainable with IIoT. He also encourages the supplier and user communities to do pilot programs to flesh out prescriptive technology.

“There is not a barrier to prescriptive from the technology viewpoint,” says Rio. “The next step is really to understand how the technology would be melded into products and designed in a fashion that can be applied by end users and deliver ROI.”

To facilitate this effort, he strongly advises engaging with a global service provider that has all of the necessary IIoT technology skills already available to them, particularly industrial automation, DCS and PLC systems, data historians, networking, the cloud, and security.

E-mail Contributing Editor
Sheila Kennedy, CMRP, managing director of Additive Communications, at sheila@addcomm.com.
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Too many companies continue to stagnate in the mindset of descriptive analytics, and they haven’t moved forward to predictive or prescriptive analytics.

“Advanced analytics is a business process, not code or an algorithm, that solves a problem statement,” says Chad DeJong, program manager at Factora (www.factorasolutions.com), who argues that we must shift our mindsets related to the collection and use of data in order to get the most out of all the information we collect.

**Smart Industry:** What’s an underutilized technique for turning data into a competitive advantage?

**Chad DeJong:** Big data remains a buzzword that everyone talks about, and I suppose that is because data volumes continue to explode. As companies collect more and more data, analytics tools need to evolve to do more. In my opinion, the tools and techniques are not keeping pace with data. Of course, that is no fault of the software itself. There are hundreds of analytical software choices out there, both commercial and open-source, which can execute any algorithms that users can code. No, the critical path here is our own vision of how to use the data.
To begin, professionals must challenge themselves to be more thoughtful about what business problems they want to solve. Ideally, this is done before the data is architected and collected, not after. Data scientists can implement a wide array of advanced modeling techniques, but it will be misguided without solving a specific, measurable business question.

Second, far too many companies continue to stagnate in the mindset of descriptive analytics, and they haven't moved forward to predictive or prescriptive analytics.

Another way to utilize data in a more powerful way is to apply it to operations-research techniques, such as dynamic simulation or optimization models. Dynamic discrete-event simulation models are built to describe the combination of multiple dependent and independent events in concurrency and over time, and as such they can be very data-thirsty. These simulation models often shine in very complex environments, where point-in-time algorithms (Neural Nets, Decision Trees, etc.) can fail. Connecting discrete-event models to real-time data sources is the perfect marriage.

**SI:** How has the world of data changed for industry/manufacturing in recent years?

**CD:** The new catchphrase is “Data is the New Oil.” I’m not sure who first coined that phrase, but I’ve seen it in several major publications recently, and I tend to disagree. Oil is a finite resource, can be stored for many years, and only a handful of people can mine it. None of these are true of data. The good news is that smart manufacturing has hit the tipping point. There are now, technology-wise, many reasonable routes. Unlike ten years ago, you no longer have to invest in an intimidatingly large, complex platform. There are many choices in technology, vendors, and scale.

Again, with unprecedented volumes of data, it is increasingly difficult for one person or a small group of people to sufficiently handle it. The demand is growing, as the democratization of data is a significant driver in analytics. Users demand new solutions that provide access and visibility to data. Technologies that cannot proliferate information and scale across user bases are becoming extinct.
**SI:** What industries are pioneers in capitalizing on the value found in data? What industries are lagging?

**CD:** This second question is very tough, as every industry segment I can think of is now using data and analytics in very profound ways. Wherever there is an immediate and direct payback for analytics (i.e., where the commodity itself is money), that is where we can find cutting edge data analytics.

So, the biggest champion of data and analytics has been finance. What we call data science today has long been used to evaluate hedge funds. The gambling industry aligns to the classic theories of probability and payoffs. Retail banking and insurance are both in the business of risk management, and as such, their lifeline depends on customer analytics and product analytics.

More recently, e-commerce and media have been very active industries. They collect, analyze, and utilize customer insights by leveraging social media content on billions of mobile devices. Net Promoter Scores (NPS) are tracked and continuously updated—the willingness among customers to recommend a company or its products/services. Anyone with an account at Amazon or Netflix understands how history and personal preferences are now used instantaneously to predict future activity.

Of course, smart manufacturing is also making great strides within the Industrial Internet of Things (IIoT). Sensor-based devices can monitor industrial processes and generate a steady stream of status updates. The interpretation of this data must happen in milliseconds, so that machines are allowed to continue feeding materials, show KPI trends, or trigger interventions in case of any number of potential problems. The manufacturing industry also uses data for supply-chain management and optimization—think geographic placement of distribution centers, routing finished goods to the appropriate warehouse, locating preferred raw material vendors.

**SI:** How does big data prompt us to “move away from the machinery”?

**CD:** As a formally trained industrial engineer and a disciple of lean manufacturing, I’ve never been completely comfortable with the
idea of “moving away from the machinery”. The Gemba walk remains the first step in any continuous improvement initiative, and helps teams answer the critical question: “What business problem are we trying to solve?” However, the spirit of this question is indeed aligned with continuous improvement. Smart manufacturing leverages digital data to solve problems and improve manufacturing performance, with insight never available or even imaginable before. This is essentially the fourth industrial revolution. It’s about big data and predictive analytics and artificial intelligence. The IIoT provides an environment of connected sensors which can gather data about the shop floor environmental conditions, current work, and equipment status. Data collected from factory equipment can help determine the health of the machinery and identify potential issues. This sort of predictive maintenance can curb lost productivity and potentially extend the life of the factory machinery.

Smart manufacturing can help us turn the focus from what the equipment is doing, to what the equipment is telling us. With smart manufacturing, the machines tell us what to do. Thus, we can constantly focus on getting more out of machinery, every minute of every day, without physically being at the machine. Traditionally, lean has been an unwilling or cautious partner with IT solutions. That is no longer the case, as data and IT solutions are almost a requirement for any modern continuous-improvement program.
Preventive maintenance (PM), predictive maintenance (PdM), condition monitoring... as soon as plants begin the journey away from reactive activities to more proactive ones, a new strategy is introduced. This dilemma may leave some maintenance technicians and managers feeling as if they are always behind.

One new strategy is prescriptive maintenance. What exactly does this mean? To use the definition from the 2017 Plant Services article “RxM: What is prescriptive maintenance, and how soon will you need it?” (http://plntsv/BEST17-28), “[Prescriptive (Rx)] maintenance is unique in that, instead of just predicting impending failure, as PdM does, it strives to produce outcome-focused recommendations for operations and maintenance from the Rx analytics.”

Many plants, especially those operational for some time, are beginning to implement preventive strategies and making the turn from a reactive culture. They are often not in the right place in the journey to add prescriptive methods. However, there are five tactics that teams can apply in order to move in the right direction and lay the groundwork for prescriptive strategies.
1. GATHER WORK PROCESSES THAT SUPPORT BEST PRACTICES

The Baldridge Glossary states, “The term ‘work processes’ refers to your most important internal value creation processes. They are the processes that involve the majority of your organization’s workforce and produce customer, stakeholder and stockholder value.”

Often, organizations de-emphasize the development of long-term strategic work processes, and instead try to solve short-term problems or simply install a new software solution and move on, ignoring long-term root causes. The lack of an overall strategy and an overreliance on IT are likely to lead to disparate asset management tactics.

Asset management programs may fall short because the organization has concentrated its efforts on technology without addressing underlying problems. A successful work process program must begin with the right strategy for managing assets, then focus on the people and processes, and then the technology needed to carry it out.

2. GATHER AN ASSET REGISTRY WITH HIERARCHY AND CRITICALITY

Is the location and information for every asset in operation and its backup known and recorded in a centralized place or database? If not, taking a full inventory of each asset is recommended, ideally recording this information in an enterprise asset management (EAM) or computerized maintenance management software (CMMS) system. The benefit of a CMMS is that all maintenance activities are stored in one system, and the maintenance team can configure it so that it includes failure mode information and other maintenance specific information that the team requires.

Is the asset criticality of failure clearly defined, or at best objectively analyzed against proper risk assimilated rankings? Criticality ranking is conducted based on the assumption that the plant operates at 100 percent capacity, and the only failure is on the functional location being ranked. The failure of the functional location being ranked should be a typical failure type of that location and not an extreme failure that may have happened once in the past.

According to Life Cycle Engineering, “The asset criticality ranking is used to help prioritize maintenance work and to identify the most critical assets — the top 10 percent or 20 percent — for further analysis ... By identifying the characteristics that make each asset critical, the analysis will also provide valuable information to decide what actions will reduce risk for all plant assets.”

https://www.lce.com/Why-is-Criticality-Analysis-important-1204.html
3. BEGIN CONDITION MONITORING

Even if a plant begins by only placing sensors on its bad actors, this first step allows the maintenance team to acclimate to the idea of wireless sensors and the data they provide during continuous monitoring. The suggestion is to start small and get some wins that can be communicated to the team, senior management, and other stakeholders to prove the benefits of the technology. Some technology types that are possible first choices are vibration, ultrasound, oil analysis, thermal imaging, temperature sensors, and power monitoring.

Continuous monitoring provides many benefits, including historical data for baselines and benchmarks. These baselines can be used as parameters for alarms. These data are also required for any prescriptive and/or machine learning to occur. As wins and successes are recorded and reported, other technologies can be added to build up to predictive and then to the realm of prescriptive capabilities.

4. PLAN FOR DATA INTEGRATION

Regardless of the system and sensors selected to gather data for predictive analytics, consider looking for a system that can be integrated with legacy systems, including supervisory control and acquisition data, building management, and other process data systems. This integration should be planned for ahead of time to minimize more equipment and technology purchases in the future.

Data is the lifeblood of any solution. The ability to manage and maintain assets depends largely on the quality of data available about them and managing that data to produce actionable data to send to the CMMS/EAM system so that activity is driven by the condition of the assets. If data quality and management are not assessed and optimized before a program is implemented, all these inefficiencies will simply...
reemerge, creating the same problems in the new solution.

5. START A CULTURE-CHANGE CONVERSATION
Humans are creatures of habit, and changing how and when they do things, particularly the work they do 8 or more hours per day, five or more days per week, is not easy. Even if the change will provide benefits and help everyone work smarter within the plant, the implementation of new technology and processes may be resisted.

As the plant begins to build its asset health management based on measured parameters instead of calendar-based activities, begin conversations with the technicians, senior management and other stakeholders. Get their buy in and understanding of how these new methods for maintaining assets will benefit the entire plant before the first piece of technology is purchased, and if possible, include the team in some of the decision making.

Serving as a Certified Reliability Leader with nearly 2 decades of experience in maintenance and operational best practices, Greg Perry, CRL, is dedicated to positive client relationships while bringing to the table a broad base of experiences in the areas of MRO and storerooms, planning and scheduling, world-class maintenance principles and world-class CMMS consultation and leadership. He is a senior maintenance reliability consultant with Fluke Accelix (www.accelix.com). Contact Greg at gregory.perry@fluke.com.
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Efficient production and manufacturing depends on the harmonious contributions of multiple parties and machines. All must work together to ensure that production schedules are kept and the quality of end products meet client demands.

Despite operating within an industry where machine disruptions and delays significantly affect the bottom line, many companies continue to employ reactive strategies when managing production road blocks. It’s time to implement predictive maintenance strategies in the manufacturing process to save both time and money.

**DETECT**

Early detection on potential machine failures is the goal for all predictive maintenance programs. Early detection allows maintenance teams to plan for repairs or change outs during planned outages to minimize downtime.

Vibration and ultrasound tools are at the heart of a good predictive maintenance program. Vibration will detect machine issues like unbalance, misalignment, looseness, etc. early enough that they can be corrected to prevent bearing failure. Once the bearing starts to fail, ultrasound will find those faults first – an early warning that can be monitored. Bearing faults will show up in the vibration spectrum as the fault progresses.
Vibration and ultrasound measurements can be trended to monitor machine health. These technologies work together to help us understand what actions can be taken to correct the problem early. They can also predict how much time we have to plan maintenance.

Trending is a very important part of the predictive process. Velocity is measured in inches per second (ips) or millimeters per second (mm/s). These measurements are compared to ISO 10816 Alert and Alarm levels. Exceeding the alert levels is the first indication that your asset has a problem.

Ultrasound is measured in decibels (dB). Ultrasound standards developed by NASA can also be compared to the ultrasound trend. Compared to the collected baseline, an increase of 8 dB is an indication that a bearing is under lubricated.

Lubricating the bearing will lower the ultrasound level back to an acceptable level and a new baseline can be established. An
increase of 12 dB means that the bearing has moved into late-stage bearing failure.

**ANALYZE**

We watch trends until we get an alert or alarm. Once the measurement has exceeded ISO acceptable vibration levels, it’s time to analyze the data. This can be done by trained analysts, online analysis tools, or remote third-party professionals.

Once we know something is wrong, we need to find out what it is. Analysis can tell us how to mitigate the problem so we can catch it early. Faults like unbalance, misalignment and looseness cause the majority of machine problems, leading to bearing failure, and early intervention can prevent machine failure.

Once we have identified a problem, we can analyze the data for comparative analysis of like-machines. The results can be applied to the other motors, pumps, fans, compressors, etc. to ensure that the same fault isn’t present. Many problems we encounter with

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**Figure 2.** Using vibration and ultrasound trends together provides a strong picture of machine health.
our machines are a result of the installation process, so if all of the pumps and motors in the pump room were installed at the same time, it makes sense to another inspection to rule out the fault.

A complete Failure Mode and Effects Analysis (FMEA) should be performed to determine root cause and eliminate and prevent this fault from occurring in the future.

CORRECT
Detection and analysis are a big part of the process, but correction is where the rubber meets the road. Determining when to intervene can be difficult. Here are some questions to ask:
- Can or should production be interrupted to perform the repairs?
- What is the cost of repair and downtime if we run it to failure?
- When is our next maintenance outage and will it last that long?

Once a machine fault is found, it needs to be documented. Planning and scheduling needs to happen. Parts and the proper tools need to be part of the planning and scheduling process, as well as the scheduling of the technicians and millwrights with the training and knowledge to do it right the first time.

CONCLUSION
Detecting, analyzing and correcting maintenance problems early can reduce maintenance costs by as much as 50% and increase uptime by as much as 30%. Proper training to use and apply predictive maintenance tools is essential to your success. Not only training to use the tools, but certification training to understand and analyze the data you collect from your machines is also critical.

Predictive maintenance solutions are becoming less expensive, simpler to use and ubiquitous. Is this your year to start a PdM program?

Paul Berberian is a Condition Maintenance Specialist at GTI Predictive Technology (www.gtipredictive.com). Contact him at paulb@gtipredictive.com.
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Dynamic monitoring for dynamic processes

Order tracking conquers signal smearing and generates meaningful data
by Greg Lee, PRUFTECHNIK

Many machines do more than just run at a fixed speed. Lots of machines speed up, slow down, adjust loads, and reverse direction. In other words, they dynamically adjust to their process environments and missions. Wire saws that cut silicon wafers, winders that collect materials onto large spools, container ship cranes that load and unload ships, mining drag lines, wind turbines, and ship bow thrusters represent just a few of the machines that confront ever-changing process environments and respond to them flexibly and dynamically.

These machines are terrific! However, the very flexibility that makes machines like these so valuable in industry also creates a unique maintenance issue: their performance monitoring and vibration analysis can be challenging. Machinery that carry out dynamic processes require performance monitoring techniques that are just as dynamic. A technique termed “Order Tracking” hits this dynamic monitoring nail right on the head.

SIGNAL SMEARING: WHAT’S THE PROBLEM?
To evaluate performance on rotating machines, collecting accurate frequency data is essential. But with speed or load changes, data collection methods and analysis that were designed for stationary signals just don’t work. Many machines never settle into a constant operating speed. Many never face stable load pressures.
In these kinds of dynamic process environments, accurate and precise frequency information is difficult to come by. Conventionally collected signal data are smeared or skewed. The signal is full of “noise”. Simple Fast Fourier Transform (FFT) analysis is not enough. The data are useless.

Instead, dynamic processes require dynamic monitoring. Dynamic process monitoring using Order Tracking is a way of sampling signal frequency as a function of revolutions per minute (RPM) instead of speed. Using a tachometer to integrate RPM information into sampled data, Order Tracking can produce waveform spectrums that are clear and concise even when there are radical changes in machine speed.

When waveform data is collected for Order Tracking spectrums, it is accumulated at a fixed sample rate that is determined according to the spectrum requirements of F-Max and resolution. The result is a waveform generated over time (see Figure 1). Note: F-Max describes the graph’s maximum x and y values, i.e. the parameters of the spectrum graph.

Next, a tachometer signal is overlaid on the data. The lowest speed recorded during the waveform capture is used to “post process” the waveform. In essence, an RPM overlay is used to resample the data, changing the time units of the waveform to RPM units (see Figure 2).

Once the RPM information is integrated into the data, the spectrum is calculated. The spectrum frequency is listed in orders of running speed. Thus, even non-speed
synchronous vibrations, such as bearings, show up as a multiple of running speed (see Figure 3). Accordingly, if an inner race frequency is, for example, 6.2 times the running speed, then the spectrum peak for that inner race will be found at 6.2 times the running speed.

Comparing Vibration Frequency Spectrums

Side by side waveform spectrums of vibration data provide a useful comparison between conventional spectrums and Order Tracking spectrums. The examples in Figure 4 illustrate a velocity spectrum. Both were measured as the machine speed was changing. The figure on the left presents waveform data that was conventionally sampled and shows the smearing of the spectrum. The result shows no vibration at a discrete running speed but a range of low amplitude peaks smeared over a range of frequencies. In contrast, the figure on the right was produced using Order Tracking. It is now easy to see the vibration at running speed (together with additional harmonics) as well as some bearing frequency noise.

An acceleration spectrum without Order Tracking similarly generates signal smearing as machine speed changes during measure-
ment (see Figure 5). On the left, the amplitudes of the smeared spectrum are greatly reduced, and there is no clear sharp peak at running speed. Once again, the spectrum on the right, collected with Order Tracking, is clear and well defined.

Pinpoint diagnosis of a maintenance problem using Order Tracking can be simple. An envelope or demodulated spectrum such as the one illustrated in Figure 6 can easily reveal bearing defects in the early stages of damage. The spectrum on the right, taken with Order Tracking, clearly shows the bearings’ outer race frequency in the largest peak with several harmonics. In addition and more importantly, this spectrum reveals the inner race defect and its harmonics. Without Order Tracking, an envelope or demodulated spectrum is of little or no value.

WORK AROUNDS ARE POSSIBLE, BUT NOT PREFERRED
There are ways to get along without Order Tracking. There are work arounds that may approximate Order Tracking results, but these methods are cumbersome and lack precision.
For example, sometimes operators and engineers try to Quick Capture data. That is, they try to capture a quick snapshot of a waveform during short periods of time when a machine’s speed is constant. This waveform can then be used to calculate a spectrum covering that brief period. However, capturing meaningful waveforms in a fleeting window is a bit tricky with only a vibration data collector (see Figure 7).

It is crucial to start the measurement at just the right time. How to find that starting point is often more or less a guesstimate, and that guessing process has predicable impacts on data reliability. An amplitude trigger can help target the starting point, and software can do the post-processing to retrieve the desired spectrum, but on the whole, the Quick Capture method is finicky and risky when reliable data is needed.

Sometimes there is never a period during operation when a machine’s speed is constant, so the Quick Capture method will not work for producing a usable spectrum. In this circumstance, another possible workaround is Bulk Data Capturing. When a ma-
Machine continuously changes running speed. It is used to reduce the effect of vibration not related to the rotating speed of the machine or of interfering, nonsynchronous vibration from other external sources. An Order Tracking spectrum, on the other hand, incorporates RPM data with vibration information and is uniquely able to monitor and evaluate multiple aspects of rotating machine condition and operation.

**CONCLUSION**

Detailed component analysis on a machine that continuously changes speed is a challenge. With Order Tracking, the ability to collect meaningful signal data and calculate waveforms and frequency spectrums is made simple. For machines with dynamic process requirements or environments, Order Tracking’s dynamic monitoring spectrums are the solution.

Greg Lee is director of PRUFTECHNIK Academy and has 34 years of experience as a vibration analyst. Contact him at greg.lee@pruftechnik.com.

*Figure 7. A real-life available time window of eight seconds for collecting waveform data from a turret gearbox on an electric shovel.*
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Imagine a vibration transducer mounted close to the load zone of a bearing (Figure 1). Also imagine that when a rolling element passes a specific position on the outer race, a spectrum analysis is performed of the transducer output signal. The time frame on which the spectrum analysis is based is very short, catching only the exact moment when one rolling element passes the specific position.

In a healthy bearing, the signal is normally dominated completely by low frequency signals, such as unbalance, belt vibrations, misalignment and similar sources. Usually, there is also an extremely weak signal originating from the material interface between the rolling elements and the outer race. The small (microscopic) surface irregularities collide and emit weak elastic waves. These elastic waves are several magnitudes weaker than the low frequency signals. Since these elastic waves are very “sharp” (have short rise and fall time), they also contain energy in the high end of the frequency spectrum. One can say that it is like a “mechanical noise floor” in the spectrum.
Figure 2 illustrates a snapshot of a spectrum when a rolling element passes close to a vibration transducer in a healthy bearing. The pattern is normally dominated completely by low frequency signals (unbalance, misalignment and similar sources denoted 1X, 2X). A very weak broadband mechanical noise floor is illustrated in red. The mechanical noise floor is lubrication dependent.

In a Stage 1 bearing damage, when one or more microscopic cracks are widened the loading and unloading process - when the rolling element passes the area with microscopic cracks - creates elastic waves. The waves originate mainly from small surface collisions when the metallic parts are moving relative to each other (see Figure 3). The energy content of these elastic waves is still very low in Stage 1, but measurable. The signal pattern still is completely dominated by the low frequency energy from unbalance and similar sources (denoted 1X, 2X).

In a Stage 2 bearing damage (see Figure 4), the microscopic cracks have formed a crack network. The loading/unloading process creates stronger elastic waves because there are now more semi-loose parts under the surface and the relative movement is greater. The mechanical noise floor has grown in the spectrum but is still weak. At this stage, the waves are strong enough to trigger the natural frequencies of the bearing assembly. The bearing natural frequencies depend on the dimensions of the bearing and how it is mounted. Typically, the natural frequencies can be found in the 2-6 KHz range.

Figure 2. A snapshot of a spectrum when a rolling element passes close to a vibration transducer. In a healthy bearing, the ‘mechanical noise floor’ is very weak.

Figure 3. The mechanical noise floor has increased in Stage 1, and the signal pattern is still dominated by low frequency signals.
In a Stage 3 bearing damage (see Figure 5), the crack network has caused bigger loose or semi-loose parts. Elastic waves are created from collisions between the rolling elements and the parts. The natural frequencies of the bearing are now stronger (because the elastic waves contain more energy) and the mechanical noise floor is peaking.

In Stage 4 bearing damage (see Figure 6), the spalls have become big pits, and at the end of Stage 4 the sharp corners have all been worn down. The rolling elements are partly following the profile of the spalls, hence creating vibrations (not elastic waves) with a frequency corresponding to the bearing frequencies (BPFO, BPI, BS, FTF).

With reference to the red spectrum lines (BPFO, BPI) representing the bearing frequencies in Figure 6: how is it possible to detect early damages in Stages 1, 2, and 3 if the bearing frequencies only show up in the spectrum at...
Stage 4? This is a common misconception. When a rolling element passes the damaged area in Stage 1, there is an increase in the mechanical noise floor every time it passes that specific position. By looking at e.g. frequencies above 10 kHz and measuring the occurrence frequency of the elevated noise floor, the bearing frequencies show up. Another way to describe this is by saying that the mechanical noise floor is modulated by the bearing frequencies.

For example, a machine running at 1500rpm has a bearing with BPFO = 5.7. This means that one position on the outer race will see 1500*5.7/60 = 142.5 passes per second of a rolling element. This equals 142.5 Hz. The spectrum shown in Figure 7 is a typical Stage 1 pattern in which the red mechanical noise floor will grow and weaken 142.5 times per second. The 142.5 Hz is the occurrence frequency of the outer race signal.

When vibration enveloping was introduced several decades ago, it became possible to detect damages in earlier stages than before, and it then became relevant to talk about realistic pre-warning times. With vibration enveloping, it was possible to extract information coming from gears or bearings even if the transducer signal was dominated by low frequency content typically originating from unbalance forces.

Advances in vibration analysis technology is conservative, it takes a long time between the innovations. HD ENV Technology (HD = High Definition Enveloping) was introduced in June of 2015 on the global market and applies HD technology to signals from standard IEPE compatible transducers (accelerometers).

HD ENV is a novel approach to the task of detecting gear and bearing deterioration in very early stages. By combining low noise hardware design and patented algorithms for digital signal processing with a standard vibration transducer, it is possible to extract relevant gear and bearing information from a noisy environment with exceptional clarity.

SPM Instrument Managing Director Ron Kittle brings 20+ years of experience in wireless and on-line condition monitoring across many industries. He studied at the National Institute of Electronics and holds certifications in predictive maintenance such as thermography and vibration analysis. Contact him at ronkittle@spminstrument.com

Figure 7. Bearing failure process Stage 1 in which the red mechanical noise floor will grow and weaken 142.5 times per second.
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Airborne and structure-borne ultrasound has been around for more than 50 years. In the technology’s early days, the main application was compressed air leak detection. Even today, that’s still the most widely used application for airborne ultrasound.

Over the years, through advancements in ultrasound instrumentation and software, more maintenance and reliability personnel have begun to use ultrasound technology for more than just compressed air leak detection. Three applications in particular have seen a large increase in use: condition monitoring of bearings and rotating equipment, condition-based lubrication using ultrasound, and electrical inspection of energized electrical equipment.

Ultrasonic equipment detects airborne and structure-borne ultrasounds normally inaudible to the human ear and electronically “transposes” them into audible signals that a technician can hear through headphones and view on a display panel as a dB level. On some instruments, incoming sound can also be viewed on a spectral analysis screen that shows either the FFT or the time wave form. With this information, a trained technician can interpret the bearing condition to determine what, if any, corrective action is needed, and the current data can be compared on the spot with the baseline data.
ULTRASOUND TECHNOLOGY HAS MANY ADVANTAGES:

• It can be used in virtually any environment.
• Learning to use ultrasound technology is relatively easy.
• The technology is relatively inexpensive.
• Modern ultrasonic equipment makes it easy to track trends and store historical data.
• Ultrasonic technology has proved itself to be extremely reliable as a predictive maintenance tool, helping organizations save thousands of dollars and hours of productivity.
• There are remote monitoring options for both mechanical and electrical applications.

Airborne and structure-borne ultrasound instruments are an extension of the user’s sense of hearing. Similar to how vibration feels what you can’t feel and infrared cameras see what you can’t see, ultrasound hears what you can’t hear. There are sounds in a typical manufacturing environment (machines running, etc.) that prevent us from hearing other sounds, such as compressed air leaks or electrical discharges such as corona, tracking, or arcing. Ultrasonic instruments listen for sounds that are not present in our normal audible range.

Typically, the sounds outside normal human hearing are high-frequency sounds. The high-frequency sounds are detected by the instrument and translated through a process called heterodyning into an audible sound that the inspector hears in the headset. The unit of measurement for sound is a dB level, which is indicated on the display of the ultrasound instrument.

WHY REMOTE MONITORING WITH ULTRASOUND?

Remote monitoring with vibration analysis and temperature has been available for many years. For ultrasound, remote monitoring is a fairly new addition to the technology’s repertoire of capabilities. When you’re considering adding ultrasound to your condition monitoring program, your decision will depend ultimately on which assets you would like to monitor. Once you have determined the assets that you would like to monitor, you need to identify the failure modes related to those assets. Understanding how those assets will fail will help you determine which condition monitoring tool can be applied to find those failure modes.

Ultrasound is a proven technology that can detect certain mechanical and electrical faults much sooner than other technologies can. By sensing subtle changes in ultrasonic amplitude, ultrasound is adept at finding early-stage premature bearing faults, as demonstrated by the I-P-F curve.

Ultrasound plays a critical role in helping extend the life of bearings in the I-P interval by condition lubrication of bearings. Studies have shown that the majority of premature bearing failures can be attributed to lubrication errors. Whether it’s over- or under-
lubrication, using the wrong grease for the wrong application, or lubricant contamination, it all comes back to improper grease application. Ultrasound can prevent over- and underlubrication, thus potentially eliminating a large number of bearing failures.

When a bearing lacks lubrication, there’s an increase in friction. The higher friction also increases the amount of ultrasonic noise the bearing produces; this is indicated by a rise in the decibel (dB) level. When greasing a bearing that needs lubrication, one should see a gradual decrease in the dB level. Once the dB level has fallen back to a normal or baseline level, greasing can cease. If the bearing already has sufficient grease, then the dB level will slowly begin to rise as more grease is applied. That’s because overlubrication also increases friction in the bearing housing, thus producing a higher dB level. The inspector would notice the rise in dBs as grease is applied and would stop greasing.

In the P-F interval, once a failure has begun, ultrasound is excellent at finding it. These are bearing failures that can be detected even before changes in vibration are. If you’re monitoring critical assets, ultrasound and vibration should be used together in an effort to potentially detect multiple failure modes that may be missed when using one technology alone.

REMOTE MONITORING - MECHANICAL INSPECTION
Remote monitoring of bearings and other rotating equipment with ultrasound can be done one of two ways.
The first is by using wired remote access sensors (RAS). The sensors are mounted to the assets when it is safe to do so, and the cables are brought out to a safe area (outside of guarding) where they can be connected directly to a portable handheld ultrasound instrument. The cable lengths for the ultrasound remote access sensors can be made to up to 100 ft (30.48 m).

The ultrasound remote access sensors can also be connected to a junction box or a switch box. As many as 12 ultrasound remote access sensors can be connected to one switch box. Similar to the way vibration-analysis switch boxes work, the ultrasound sensors are connected to the switch box along with the handheld ultrasound instrument. During analysis, the inspector turns the dial to the next point to collect a reading.

Remote monitoring with ultrasound can also be done continuously via a sensor that offers an audio output for easy connection to plant process monitoring systems. This audio output will allow for sound recording for further diagnostics or for comparing baseline sound files with alarm level sound files. With adjustable alarm levels and dB threshold settings, this type of sensor can be used to track alarm conditions and trend potential problems.

**REMOTE MONITORING - ELECTRICAL INSPECTION**

Ultrasound can be used to inspect almost any energized electrical equipment. This may include metal-clad switchgear, transformers, substations, relays, and motor control center, along with many others. Ultrasound can be used to measure equipment voltages from the low end (110 volts) to well over 12,000 volts (12kV).

Traditionally, inspection of energized electrical equipment has been performed using noncontact infrared cameras. However, increasingly, ultrasound is being added to these inspections. One of the main reasons has been safety: An ultrasound inspection of electrical equipment can be done without the need to open the energized cabinet or enclosure. The handheld ultrasound instrument is used to scan openings on the cabinet. The high-frequency sound produced by corona, tracking, and arcing from inside the enclosure will exit through the openings. The inspector will hear the sound via the headset and know an anomaly is present. The sound can then be recorded to determine whether the condition is
corona, tracking, arcing, or some type of mechanical looseness.

Corona refers to the ionization of air surrounding an electrical connection higher than 1,000 volts. Corona by nature does not produce significant heat that would be detected by an infrared camera. However, it does produce high-frequency sound that can be detected by the ultrasound instrument. If corona discharge continues to occur, it can lead to a more severe problem such as tracking or arcing. By-products of the ionization process are ozone, electromagnetic emissions, ultraviolet light, and nitric acid. The nitric acid is a corrosive and can deteriorate insulators and connectors and lead to tracking and arcing.

When the sound file of corona is recorded, signature characteristics visible in the FFT and time wave form (TWF) will help diagnose the condition. For corona, the discharge points occur only at the highest-voltage point on the sine wave. This means that the amplitude peaks in the TWF are somewhat equally spaced as the discharges are only at the positive peak of the sine wave. The result will be well-defined 60Hz or 50Hz harmonics.

Tracking (low current pathway to ground across an insulator) and arcing (electrical discharge to ground across an insulator) also have characteristics to look for. With tracking, the discharge does not have to take place at the peak of the wave form. Instead, it can happen anywhere on the positive portion of the cycle. The spacing of the peaks in the TWF would be similar but not uniform. As tracking becomes more severe, there would be more discharge events and therefore more nonuniformly spaced narrow peaks.

Arcing has the most nonuniform “look” in the FFT and TWF. Only the bursts of the discharge can be heard, and these will be seen as wide peaks in the TWF view.

A remote mounted sensor that offers a heterodyned audio output to allow for sound recording can be a valuable tool for electrical inspection. Analyzing recorded ultrasounds of electrical anomalies is the only way to diagnose with ultrasound the condition heard. For optimum flexibility, consider an ultrasound sensor that can...
be mounted inside of an electrical cabinet such as a transformer or switchgear and wired into the facility’s process monitoring systems or a PLC.

CONCLUSION
Remote monitoring with ultrasound is a viable option for maintenance and reliability programs that are already monitoring assets traditionally with handheld devices and for programs where ultrasound is not currently in use.

Because it is complementary to vibration analysis for mechanical inspection and infrared thermography for electrical inspection, ultrasound will only enhance existing condition monitoring efforts. In areas that are remote, inaccessible, or dangerous, remote monitoring with ultrasound may be your only option. Additionally, a multitechnology approach to condition monitoring increases your chances of finding multiple failure modes and detecting them early enough to make necessary repairs before problems become catastrophic.

Adrian Messer, CMRP, is manager of U.S. operations at UE Systems. Contact him at adrianm@uesystems.com.
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