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Making maintenance smarter

Predictive maintenance and the digital supply network

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Introduction

TRADITIONALLY, most maintenance professionals have combined many techniques, both quantitative and qualitative, in an effort to identify failure modes and mitigate downtime in manufacturing facilities. But the rise of new connected technologies can enable machines to do these tasks for them, both maximizing the useful life of machine components while still avoiding machine failure.

Today, poor maintenance strategies can reduce a plant's overall productive capacity between 5 and 20 percent.[1] Recent studies also show that unplanned downtime costs industrial manufacturers an estimated $50 billion each year.[2] It can be difficult to determine how often a machine should be taken offline to be serviced as well as weigh the risks of lost production time against those of a potential breakdown. Traditionally, this dilemma forced most maintenance organizations into a trade-off situation where they had to choose between maximizing the useful life of a part at the risk of machine downtime, attempting to maximize uptime through early replacement of potentially good parts, or, in some cases, using past experience to try to anticipate when breakdowns might occur and addressing them proactively.

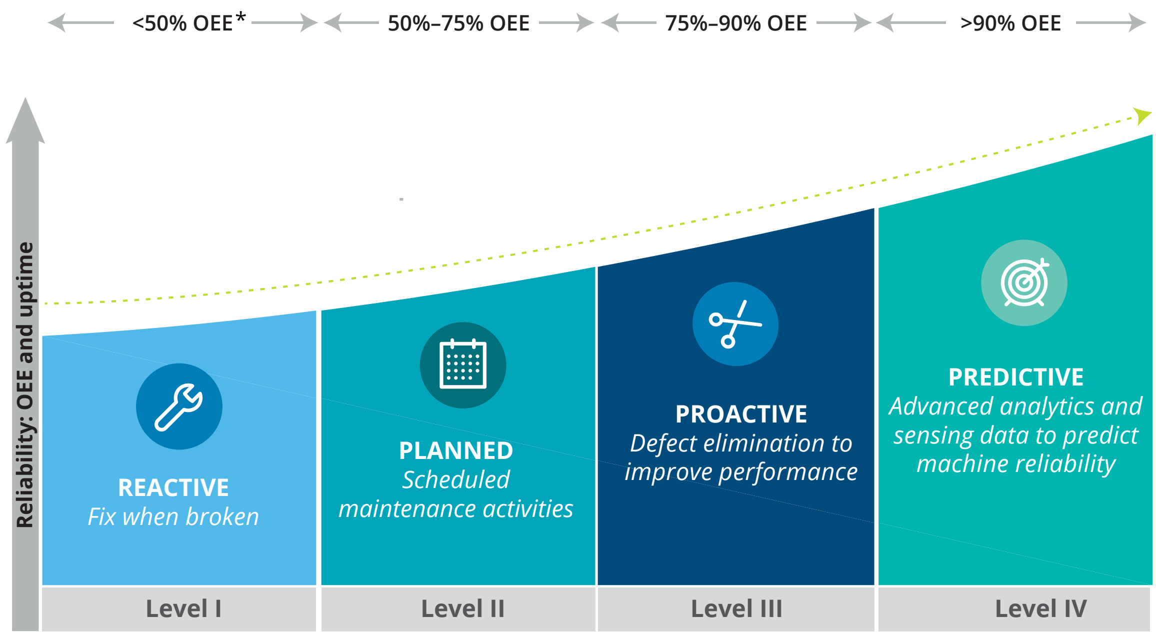
PdM is often the most efficient maintenance strategy available—a gold standard for which to aim.

Traditional components of a maintenance program often fall into four categories, each with its own series of challenges and benefits (figure 1):

- Reactive maintenance
- Planned maintenance
- Proactive maintenance
- Predictive maintenance

The fourth component, *predictive maintenance* (PdM), has become possible using smart, connected technologies that unite digital and physical assets. While PdM is not a new concept, the massive investments in technology typically needed to handle the massive volumes of data required often limited deployment to only the largest organizations. Today,

Figure 1. Maintenance strategy continuum



* Original equipment effectiveness

Source: Deloitte analysis.

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the high availability and low cost of digital technologies, coupled with the rise of the digital supply network (DSN), have made it possible for PdM to scale on a broad level across facilities and organizations of all sizes.[3] This combination of operations and information technologies can allow deeper analysis of data from the physical world and drive further intelligent action (see the sidebar "Predictive maintenance and the physical-digital-physical loop" to learn more). In PdM, data gathered from connected, smart machines and equipment can predict when and where failures could occur, potentially maximizing parts' efficiency and minimizing unnecessary downtime. In most cases, this means that PdM is the most efficient maintenance strategy available—a gold standard for which to aim.[4] In this way, PdM is often considered a critical capability in the age of the DSN.

For a closer look at DSNs—adaptive networks that replace static linear supply changes—and the role of connected technologies in driving agile, connected production, see *The rise of the digital supply network: Industry 4.0 enables the digital transformation of supply chains*.

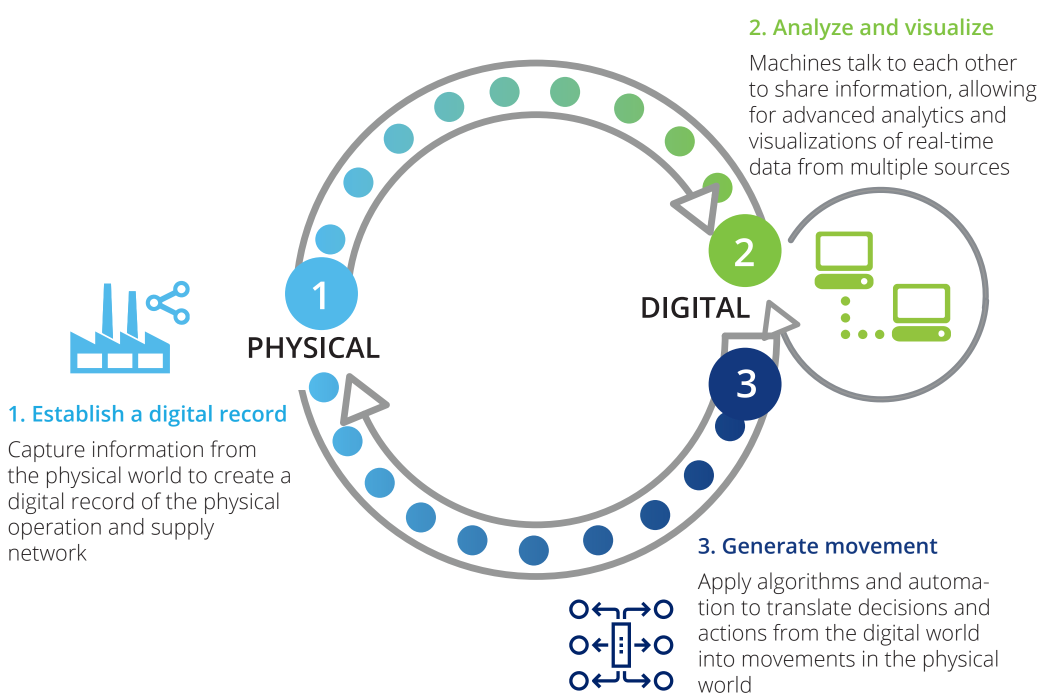
In this paper, we examine PdM: its role in the DSN, its impact and potential benefits, the technologies that underpin it, and its typical role in the smart factory. We define strategies for how to incorporate PdM into a wider asset maintenance strategy, explore some of the challenges of PdM implementation, and examine the organizational changes that can make a transition to PdM successful. Finally, we delineate a few ways to get started in implementing PdM as part of the asset maintenance strategy for the smart factory.

PREDICTIVE MAINTENANCE AND THE PHYSICAL-DIGITAL-PHYSICAL LOOP

For organizations accustomed to traditional linear data and communications, real-time access to data and intelligence can fundamentally transform the way they can manage assets and achieve objectives. Once organizations decide to adopt PdM, they should consider how to develop, implement, and use the various connected technologies that power it to drive decision making. Before doing so, however, it can be useful to consider the process of information creation, analysis, and action as a loop that constitutes the essence of how these technologies can create value. The integration of digital information from many different sources and locations drives the physical act of maintenance, manufacturing, and distribution, in an ongoing cycle.

Real-time access to data and intelligence is driven by the continuous and cyclical flow of information and actions between the physical and digital worlds. This flow occurs through an iterative series of three steps, collectively known as the *physical-to-digital-to-physical loop*. First, information is captured from the physical world and digitized (physical to digital). Second, the digital-to-digital portion of the loop focuses on sharing and analyzing data to generate meaningful insights. Finally, the loop is closed with a *digital-to-physical* transformation of those insights into real-world actions. This process is described visually in figure 2.

Figure 2. The physical-to-digital-to-physical loop



Source: Center for Integrated Research.

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In its entirety, this process allows organizations to harness data and take action in advance, rather than simply be informed by the data. The net result is that organizations can operate more efficiently or even possibly create entirely new business models, such as the DSN.

When this model is applied to PdM, companies can use data gathered from assets and machinery to ideally understand functionality and predict when breakdowns may happen or maintenance needs to occur. This can enable organizations to be more agile, take a holistic view of asset conditions, and anticipate needs.

Managing trade-offs

Current asset maintenance strategies

WHILE PdM is rapidly coming to be considered the gold standard of maintenance strategies, it may not necessarily be the best approach for every type of maintenance or repair need. In some cases, other approaches may be a more effective fit within the smart factory. For this reason, we briefly explore each below and examine how they lead up the maturity curve to PdM.

Reactive maintenance: Allowing parts to run to failure

As the least technologically advanced and most common level of asset maintenance,[5] reactive maintenance involves repairing or remediating parts or equipment only after it has broken down or been run to the point of failure. Reactive maintenance strategies offer the maximum utilization of tooling or machine components by using them to their very limits. However, this can lead to catastrophic machine damage as parts begin to vibrate, overheat, and break, potentially resulting in further damage. Similarly, reactive maintenance can lead organizations to treat the symptom rather than the problem itself, such as repeatedly addressing bearing vibration issues rather than their root cause, perhaps thermal expansion.[6] While this approach may be acceptable in machines that feature very cheap, reliable, or redundant parts,[7] for most applications, more frequent replacement of parts and servicing of equipment can be a more cost-effective strategy.

Planned maintenance: Preventing problems before they occur

By replacing parts before they fail, a planned, time-based preventative maintenance approach can help avoid broken machinery and decrease downtime by replacing parts at regular, preplanned intervals. While planned maintenance may be more cost-effective than reactive strategies, however, it also can be more difficult to justify. Because parts are replaced while they still have useful lifespan remaining, additional spare parts are typically kept on hand, adding spare parts inventory management to an already complex task. Also, planned maintenance often requires greater planned downtime, which can be difficult to justify as seemingly perfect machines are taken offline and operations disrupted.[8]

Proactive maintenance: Treating the root cause, not the symptom

Whereas planned maintenance provides a regularly scheduled time for part replacements and repairs, proactive maintenance represents a more data-driven, analytical approach. Proactive maintenance strives to identify and address the problems that can lead to those breakdowns in the first place, such as improper machinery lubrication, contamination, misalignment, or suboptimal humidity and temperature conditions.[9] By identifying and addressing these root causes of many part failures, proactive maintenance typically helps to prevent the wear and tear that leads to equipment failure, ultimately decreasing failures and downtime. Other benefits include fewer unnecessary repairs, less need for spare parts inventory, and longer lifespan of equipment and parts—ultimately reducing costs. Another advantage may be that proactive maintenance can be combined with other maintenance strategies. It is likely to be optimal for large, costly equipment that operates in challenging conditions.

Table 1 lists the benefits and challenges of these three types of maintenance.

While each maintenance strategy typically requires relatively higher levels of investment in terms of time and training, the benefits usually increase correspondingly, while the challenges can also decline to some extent.

Table 1. Trade-offs of the different types of maintenance

	Benefits	Challenges
Reactive	• Maximum utilization of tooling or machine components	• Potentially greater damage to machine beyond failed part • Unplanned downtime • Higher maintenance costs
Planned	• Less likelihood of broken machinery • Less unplanned downtime • More cost-effective than reactive	• Increased replacement costs over time • Need for additional spare parts inventory • Increased planned downtime
Proactive	• Longer lifespan of equipment • Decreased downtime, planned and unplanned • More cost-effective than run-to-failure or planned maintenance • Lower spare parts inventory	• Ongoing maintenance and monitoring • Need for organizational changes • Increased training

Source: Deloitte analysis.

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Breaking the trade-offs

The era of PdM begins

PdM can break the trade-offs of the older strategies by enabling companies to maximize the useful life of their parts while avoiding unplanned downtime, minimizing planned downtime, and saving costs. In essence, PdM analyzes data gathered from connected equipment to hopefully predict when a part will fail, and thus when maintenance should take place. Rather than running a part to failure or replacing a perfectly good part that may have many cycles left, PdM can help organizations make repairs only when—or, more accurately, *before*–needed.

Why now? The rise of PdM and its place in the DSN

The concept of PdM has existed for many years, but only recently have technologies become both seemingly capable and inexpensive enough to make PdM widely accessible.[10] In the past, PdM programs often required time-consuming manual data crunching and analysis to gain any real insights from the data being collected.[11] These strategies typically relied heavily on "tribal knowledge" estimates or required in-depth knowledge and analysis of each individual piece of equipment on an ongoing basis to stay accurate.

However, the decreasing cost of sensors, computing power, and bandwidth,[12] coupled with increasing technological advancements, has made PdM a much more viable option, and one that could be feasible to scale at an enterprise-wide level. This, in turn, has often enabled PdM's adoption. Those responsible for maintenance can gather data rapidly from connected machines via diverse sources, such as critical equipment sensors, industrial control systems, enterprise resource planning (ERP) systems, computerized maintenance management systems (CMMS), and production systems, enabling them to identify root causes that may have gone unnoticed before. A consumer packaged goods company, for example, combined sensor data with data from high-speed cameras to identify a correlation between two seemingly unrelated events that were leading to unexpected pressure build-ups and shutting down product lines. This insight helped them save $5 million in annual maintenance costs and drive efficiency across all of their plants.[13]

But simply gathering the information from sensors and systems is not enough to yield the benefits of PdM. The ability to aggregate and then analyze data can be crucial to predicting malfunctions. This often requires new capabilities for creating, handling, and making use of data. Indeed, analytics capabilities have grown increasingly sophisticated in tandem with the growth of connectivity and data, enabling organizations to make sense of the data they gather. These capabilities often constitute an important component of the DSN and the smart, connected factory. PdM employs data to better inform maintenance decisions, provide greater transparency into asset health, and enable enhanced collaboration across the network—here, in the form of aggregating data from multiple sources to maintain assets in the most efficient way. This real-time flow of information, and the ability to analyze it, can allow for greater operational efficiencies and more nimble performance by using digital data to drive physical action in the form of maintenance and upkeep. This flow and analysis embody the characteristics of the DSN (figure 3).

The constant flow of data from connected physical assets and related systems enables **"always-on"** agility, in which unforeseen situations and changing conditions in machinery can be illuminated in real time, mitigating potential damage. A **connected**

Figure 3. The characteristics of a digital supply network

"Always-on" agility

Securely, DSNs pull together traditional data sets with new data sets that are, for example:
- Sensor-based
- Location-based
- "Right-time" vs. "real-time"

Outcome: Rapid, no-latency responses to changing network conditions and unforeseen situations

Connected community

Real-time, seamless, multimodal communication and collaboration across the value network with:
- Suppliers
- Partners
- Customers

Outcome: Network-wide insights from centralized, standardized, synchronized data

Intelligent optimization

A closed loop of learning is created by combining:
- Humans
- Machines
- Data-driven analytics
- Predictive insights
- Proactive action

Outcome: Optimized human-machine decision making for spot solutions

End-to-end transparency

Use of sensors and location-based services provides:
- Material flow tracking
- Schedule synchronization
- Balance of supply and demand
- Financial benefits

Outcome: Improved visibility into critical aspects of the supply network

Holistic decision making

Based on contextually relevant information, functional silos are now transparent and deliver parallel visibility, such as:
- Performance optimization
- Financial objectives
- Trade-offs

Outcome: Better decision making for the network as a whole

Implications

Companies can achieve new levels of performance, improve operational efficiency and effectiveness, and **create new revenue opportunities**

As companies leverage their full supply networks, the **traditional barriers of time and space shrink**

Source: Deloitte analysis.

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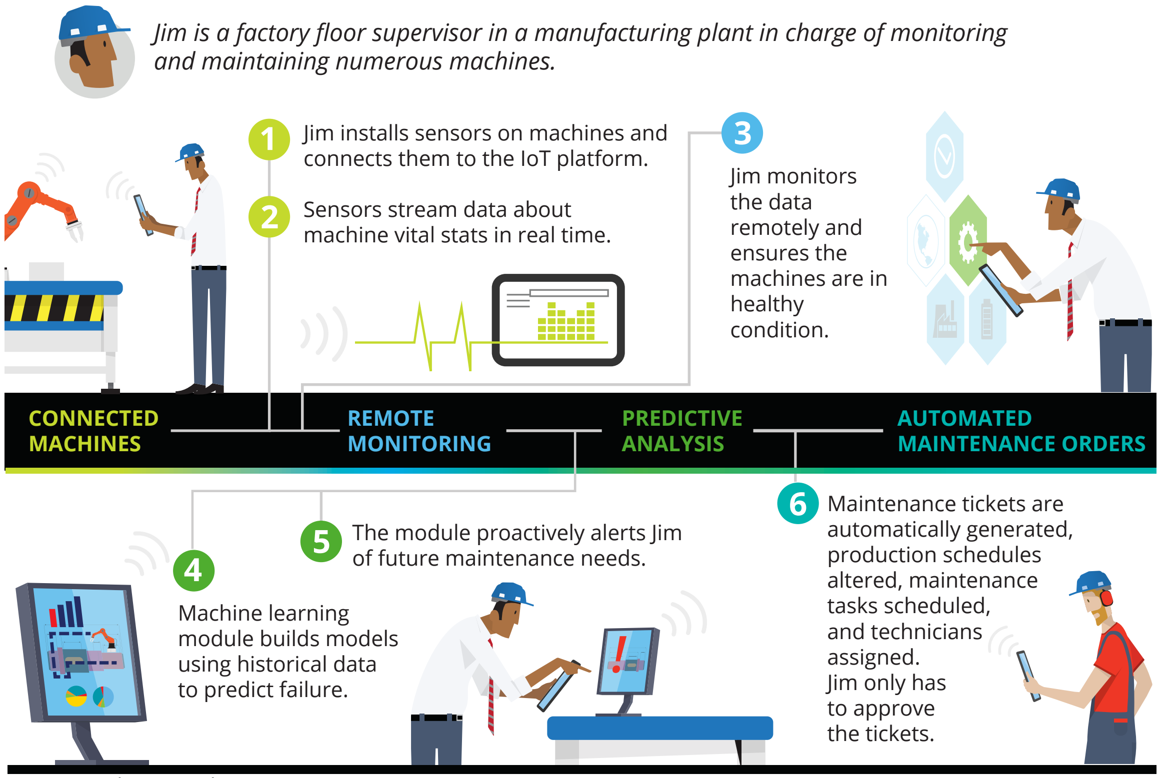
community of assets and systems can provide a greater scale and scope of data to enable more accurate predictive analysis, enabling organizations to **intelligently optimize** decision making and use of machinery. Further, aggregating the data of sensors on connected machinery throughout the production process can allow for **end-to-end transparency**, while choosing the right analytics and algorithms to make sense of those data can enable **holistic decision making** about approaches to maintaining assets, to optimize their performance based on their role within the network as a whole. Together, these capabilities can enable more informed, strategic decision making—one of the primary benefits of PdM.

Understanding how connectivity drives the PdM process

Once sources of the data are identified, networks can communicate these data across custom or standard data networks to onsite or cloud data storage. There, analytics tools with predictive algorithms analyze the collected data to determine when each individual part is likely to fail. This information is then automatically communicated to workers via data visualization and collaborations tools, which allow them to perform maintenance on only the parts that need it, when they need it. Figure 4 illustrates the PdM process.

Figure 4. The predictive maintenance process



Source: Deloitte analysis.

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The impact of PdM on the smart factory

CONNECTED digital and physical technologies typically impact two main business objectives for manufacturing companies: business operations and business growth.[14] PdM can prove valuable in both of these areas. While objectives for using digital technologies in business growth focus on top-line growth, those for operations seek to cut costs through either increased productivity or reduced risk—areas on which most maintenance professionals typically focus. When considering the number of man-hours spent performing routine machine inspections that do not lead to work orders, or spent troubleshooting unplanned downtime, the case for PdM as a tool for operational efficiency becomes clearer. Connected technologies can pull data from multiple sources and legacy systems to provide real-time advanced insights, allowing computer systems to do the legwork so maintenance managers can deploy their resources more effectively.

Improving efficiency in business operations

Connected technologies (which we explore further in the next section) help PdM address the core challenge of maintenance: the right part in the right place, at the right time. By driving those processes from real-world data, not guesses, about individual parts, PdM can help determine the optimal efficiency for most maintenance use cases.[15] PdM can reduce the time required to plan maintenance by 20–50 percent, increase equipment uptime and availability by 10–20 percent, and reduce overall maintenance costs by 5–10 percent.[16]

To illustrate, a large chemical manufacturer is actively deploying connected technologies with significant interest in predictive asset analytics.[17] The company is proactively looking to reinforce its

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leading position in asset and process management by adopting digital technologies in its "Future of Automation" program. A pilot implementation of predictive capabilities for one asset class, extruders, resulted in an 80 percent reduction of unplanned downtime and cost savings of around $300,000 per asset.[18] Now the company is expanding this capability to other critical equipment across multiple facilities.

While in reactive, planned, or proactive maintenance strategies, a wide variety of many spares is usually stocked to cope with sudden failure of parts, PdM typically allows teams to manage their maintenance process more efficiently. Consider Italian train operator, Trenitalia, which had to remove each one of its more than 1,600 trains from service not just for regularly scheduled maintenance but also when a train failed unexpectedly.[19] This created numerous delays, incurred performance penalties on contracts, and annoyed passengers. To address the problem, Trenitalia added hundreds of onboard sensors on 1,500 locomotives as part of a three-year maintenance improvement initiative. Data were transmitted to private cloud storage in near-real time, where diagnostic analytics provided advance warning of the failure of parts such as brake pads. With such data, Trenitalia was able to maximize the brake pads' useful life while reducing the number of needed spares. Overall, Trenitalia was able to decrease downtime by 5–8 percent and reduce its annual maintenance spend of $1.3 billion by an estimated 8–10 percent, saving about $100 million per year.[20] Perhaps above all other benefits, more trains have run on time, so more passengers have seemed happier.

By providing more accurate predictions of failures, and thus which replacement parts will most likely be needed, PdM allows fewer spares to be kept on hand without increasing the risk. Tying PdM systems to logistics or parts-ordering systems can further smoothen the process, allowing parts to be ordered automatically, so that the overall maintenance goal of right part in the right place at the right time is more attainable.[21] The airline industry is already using PdM to understand whether a failure is likely in the next 24 hours and what part will be needed. This should not only help to minimize disruption to the complicated daily puzzle that pairs airframes to flights but also help maintenance personnel have the right part ready when maintenance is required.[22]

Growing the business

From these statistics, it may appear that PdM is useful only when business strategies call for cost savings or greater efficiencies. Beyond operations, however, PdM may offer additional benefits with respect to business growth as well. Not only can PdM help to control costs, it can also support differentiation. Maintenance failures can impact more than simply the machine itself; they can also result in defective or poor-quality products.[23] Additionally, product quality may begin to degrade as tooling and machinery drift out of tolerance. By allowing for

greater awareness and control of those tolerances, PdM can help ensure better product quality. In addition, by reducing downtime, manufacturers can free up additional capacity on existing machinery to support growth and greater responsiveness. In this way, PdM can help ship better-quality products faster than ever before, helping to differentiate manufacturers from the competition.[24]

For example, one electronic components manufacturer was able to combine data from their manufacturing execution system (MES) and material-handling system into a set of distributed databases. By aggregating the data into a structured data feed, they were able to develop predictive algorithms that increased overall throughput and reduced quality defects by 33 percent. Most importantly, when those increases in quality are customer facing, the benefits do not end with the mere cost savings—they can have strong impacts on customer satisfaction and brand differentiation. Consider the Trenitalia example from earlier. The project aimed to improve the maintenance and reliability of locomotives, but the ultimate goal of the company was not just to increase operational efficiency in maintenance but also to improve the customer satisfaction that comes from more on-time trains as a result of fewer unscheduled breakdowns.[25]

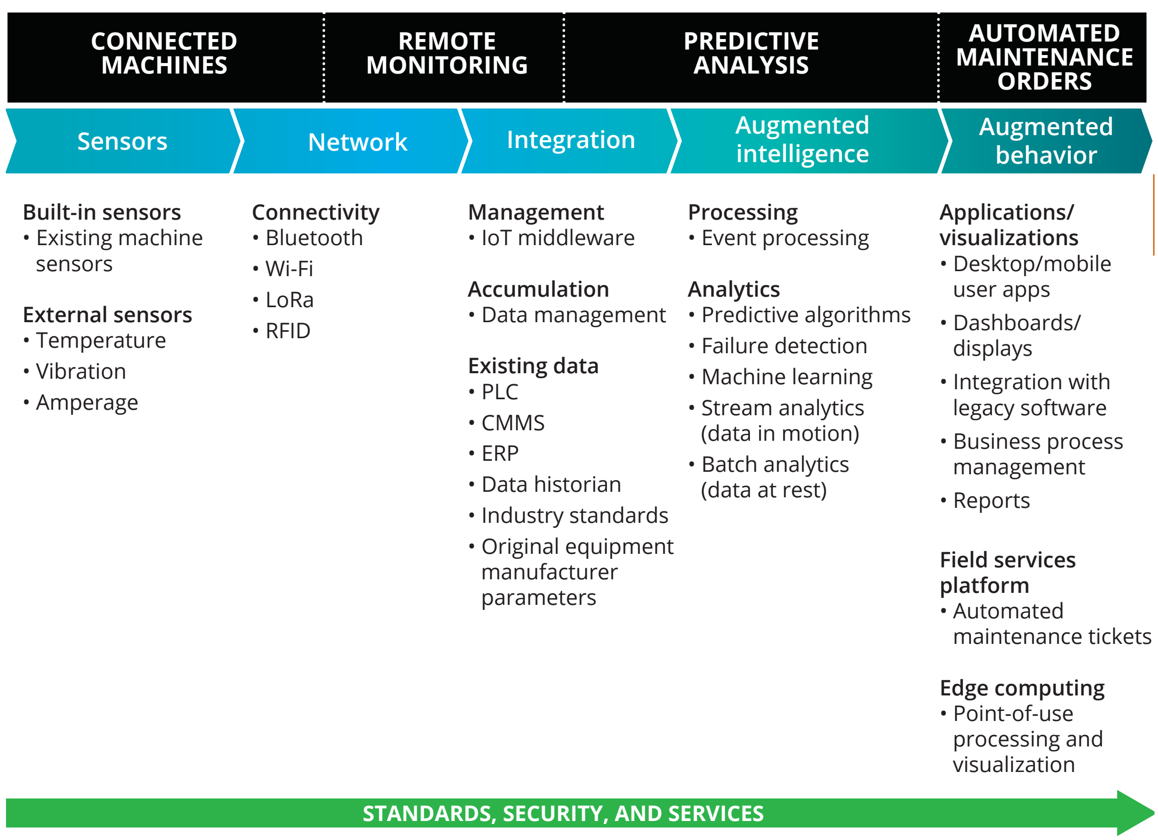
Exploring the technologies that enable PdM

UNDERSTANDING how PdM works requires an examination of the specific connected technologies that enable it: sensors and communication protocols, analytics and data-handling tools, and data visualization and collaborative tools (figure 5).

Sensors and networks

Perhaps the most important pieces of the PdM puzzle are the sensors that create the data and the communications needed to get those data to where they can be stored and analyzed. These sensors translate physical actions from machines into digital signals that communicate variables such as temperature, vibration, or conductivity. Data can also be streamed from other sources, such as a machine's programmable logic controller (PLC), MES, CMMS, or even an ERP system. GE's Condition Forecaster system, for example, uses this aggregation approach to maximize the performance and reliability of their plant motors by combining data from over

Figure 5. The technologies that drive PdM



Source: Deloitte analysis.

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As these tools move further into the mainstream, they may no longer require a degree in statistics or computer science to use, putting them within reach of many organizations that may not have had the expertise or resources to leverage them in the past.

250 sensors per motor with over 40,000 historical maintenance records.

Whether the types of protocols that enable this sort of transparency are custom-designed for a specific application or for general use such as Wi-Fi and Bluetooth, today's low cost and affordability of bandwidth and storage mean that massive amounts of data can be transmitted. This allows manufacturers to have a full picture of not only assets in a single plant but also an entire production network—leveraging the end-to-end transparency of the DSN.

Data integration and augmented intelligence

Once digital information has been centralized, it typically must be parsed, stored, and analyzed using advanced analytics and predictive algorithms. Simply gathering data on machinery from sensors is not enough. Predicting the failure of individual parts likely requires high-level solutions for unstructured data, augmented intelligence (AI), or machine learning. These technologies are needed to sift through the mountains of data to find the "signal" of a part about to fail in the "noise" of daily operation. Put simply, while PdM depends on the accuracy of failure thresholds determined in a pilot program or review cycle, machine learning technologies improve these thresholds iteratively over time by analyzing the outcomes of each prediction and adjusting the thresholds accordingly. As a result, choosing the right analytics or algorithms is a critical step in creating a PdM capability. But the results can be significant: One manufacturer recently reduced downtime on a robotic manufacturing line by 50 percent and increased performance by 25 percent by leveraging a machine learning platform for its predictive algorithms.[26]

As these tools move further into the mainstream, they may no longer require a degree in statistics or computer science to use, putting them within reach of many organizations that may not have had the expertise or resources to leverage them in the past. Operations analysts, who are more in touch with manufacturing processes, can easily create dashboards using modern application program interfaces (APIs) created specifically for the everyday user.[27]

Another trend is the movement of data to the edge. Similar to the lean technique of storing tooling at the point of use, data computation is done at the "edge," meaning it is processed at the machine where it is generated. Insights can thus be pushed directly to machine operators as well as maintenance technicians. As data continue to proliferate, edge computing reduces the overall burden on a computer network by distributing some of the processing work to a network's outer nodes to alleviate core network traffic and improve application performance.[28]

Augmented behavior

Once data have been analyzed, they can be presented to humans and machines in a manner that enables them to take action, either manually (in the case of humans) or autonomously (in the case of machines). At this stage, augmented behavior becomes relevant. Technologies such as wearables and augmented reality can allow maintainers to see large amounts of data, such as a maintenance manual or expert advice, while immersed in a task. These technologies use overlaid step-by-step instructions to help operators immediately solve problems as they arise (even in noisy environments), and help disseminate knowledge via immersive, on-demand training.[29] They also allow teams in other locations to remotely monitor and supervise operations.

For example, a leading technology manufacturer deployed a suite of industry-leading wearable technology to troubleshoot issues remotely and disseminate specialized knowledge in real time. The solution supported the manufacturing incident resolution processes, which often witnessed severe delays during critical component assembly. The company saw a 50 percent reduction in repair cycle time for defects and estimated savings of $500,000 in a single product line through reduced downtime.

Finally, after the signals have been processed, analyzed, and visualized, digital insights are translated into physical action. In some cases, the digital conclusions drawn may instruct robots or machines to alter their functions. In other cases, maintenance alerts will spur a technician into action. Consider a situation where the predictive algorithms trigger a maintenance work order in the company's CMMS system, check the ERP system for spares on hand, and automatically create a purchase request for any additional parts required, all automated and prior to unplanned downtime. Then the maintenance manager only has to approve the items in the workflow and dispatch the appropriate technician.

Laying the foundation

Building the capabilities for PdM

ADDING complex new technology to any work environment can come with considerable impacts: Greater cost and technical support, and changing talent requirements are often cited as the most significant challenges of adopting and implementing PdM.[30] Also, technology alone usually cannot help organizations transition to PdM; process and organizational change is typically just as important. As organizations seek to implement PdM, they should consider:

- **Security**. As more assets become interconnected, and with the Internet of Things becoming ubiquitous, companies should consider safeguarding access to critical equipment and adopting a proactive stance toward cybersecurity while protecting connected assets.[31]
- **New skills and organizational approaches**. Adapting to PdM can necessitate a whole new suite of skills to manage this system that goes beyond traditional maintenance planning and execution skills. Data scientists might have to work alongside reliability engineers to develop algorithms and predictive models. Many organizations find these skills hard to find and fill, and implementing solutions may require partnering with multiple vendors to augment capabilities.[32]
- **Equipment upgrades**. It is not uncommon to find decades-old equipment still in use, often making it difficult to find spares and manage inventory for replacement parts. The cost to upgrade or replace equipment with smart assets may require significant investment. On the other hand, retrofitting unconnected assets to make them a part of the smart factory can lead to increased cyber risks.[33]
- **Data management**. Collecting the *right* data, which can enable the organization to accurately predict relevant failure patterns, is crucial to PdM. Therefore, gathering the appropriate data sources to achieve the maintenance goals of the project is typically a critical first task. At the outset, this may require a significant effort in data cleansing and mapping to events to enable effective analysis. On an ongoing basis, it may require workers to adopt new practices as well. Having the right data, however, is only part of the process. Once gathered, these data can be aggregated across multiple assets and locations, stored, and analyzed by algorithms to predict failures and outcomes. It is therefore also considered important to choose the most appropriate algorithms and leverage machine learning to produce a predictive result. With this in mind, choosing and maintaining the software tools capable of this type of analysis is likely to be crucial to PdM success.
- **Technology**. Software, hardware, and algorithms focused on PdM are still in early stages compared with other approaches of maintenance. It might therefore be advisable to take a pilot approach to PdM, testing and learning before scaling up.

Maintenance strategy and processes are typically the core elements for any successful maintenance organization. Without the foundational building blocks of process and people in place, investment in technology is not likely to yield the desired results. All of the sensors and smart devices in the world are useless unless maintainers know what the values they are reporting mean.

Building organizational capabilities

Instituting a PdM process can dramatically shorten the process, bringing together and combining data from multiple assets, systems, and locations. For example, one airline company recently combined data from text files, aircraft logbooks, and maintenance records to automate this process, reducing time to insight from anywhere between 30 and 90 days down to less than a day.[34] At the same time, however, capabilities should be in place to analyze and act upon those data. Therefore, a critical step in a maintenance transformation may be to develop a decision-making framework that allows maintainers to interpret data and extract value, rather than relying on intuition and experience to make decisions. The organizational capabilities to develop this decision-making framework can be built in stages, making the process more manageable.

Stage 1: Set up a performance management framework. Understanding how "what you do" ties to "what you achieve" can be key to ensuring that metrics measure the right areas. "What you achieve" is an output and should be aligned to lagging metrics. "What you do" is controllable on a day-to-day basis—this is what should be measured on a leading basis and actively managed.

Stage 2: Set up a process to identify and capture value. Quantify the value and establish targets. Establish ownership and prioritize initiatives. Monitor performance and resource allocation.

Stage 3: Shift from reactive to proactive decision making based on real-time informational analytics. Often, this will include creating an asset information center that provides simplified access to information from multiple sources.

Assessing organizational needs

Not all companies require the same level of reliability from their assets. To assess their mission requirements and maintenance program maturity, organizations can ask the following questions:

BUSINESS STRATEGY

- What could be the value of PdM across our entire enterprise?
- How reliable do our assets need to be? What are our availability targets?

MAINTENANCE STRATEGY

- How do we determine when it's time to replace an asset rather than maintain it?
- What data do we already have that are not being used effectively?
- Have we selected an analytics tool that can handle the data types and volumes needed?
- Have we identified the critical assets in our production system?
- Are there some critical assets that would benefit from a PdM pilot?

MAINTENANCE PROCESS

- Do we have the right spare parts in the right place at the right time?
- Are our processes well documented, accessible, and useful?
- Do we have the right tools for the job?
- Do our technicians have the right skills to perform the work required?

In projects big or small, typically no maintenance organization can be successful without considering the foundational maintenance strategy and processes in tandem with the technology that enables them.

Taking the next steps toward PdM

IT often takes a confluence of the right technology, processes, and people all at the right time to be successful in the manufacturing industry, and not all organizations are going to be ready to embrace PdM right away, as they move toward implementing a DSN and a smart factory. Starting with some of the basics—preventative and proactive maintenance—can be a way to move beyond reactive maintenance while building a PdM capability. As they seek to put the foundations of maintenance in place, organizations can take several steps toward PdM:

Start small. With the basics of preventative and proactive maintenance in place, organizations can pilot PdM with one or two well-suited assets. Prime assets for one of these pilots should be both highly integral to operations and should fail with some frequency in order to create baseline predictive algorithms. Moreover, examining how these pilots fare on the defined metrics of success could allow the organization to validate the strategy, technologies, and processes while incurring limited risk.

Scale fast. Once the pilot structure is in place and has been proven on initial asset classes, PdM can be scaled up more quickly and easily to move from a couple of connected machines into an entire smart factory, which, in turn, can be connected to a wider DSN to create ecosystem-wide benefits.

This start-small, scale-fast approach to PdM can also help to uncover the unique challenges that the organization faces. For example, while some factories may have great tools and equipment, they may lack the correct documentation or training programs, or they may need to invest in more sophisticated analytics capabilities. Organizations should determine how foundational maintenance maturity will support the growth of PdM in their company. Will the work by technicians be enhanced by smart factory technologies, or will adding technology expose the weaknesses in basic maintenance understanding when the timing and execution of work orders become absolutely critical in order to avoid downtime?

Build a plan before getting started. While detailed planning can sometimes feel like a waste of time, creating a foundation such as the decision-making framework described in the previous section can be critical to identifying flaws and achieving success. During implementation, consider measuring progress along the way as important milestones are reached, such as equipping the first machine with sensors or building a first dashboard. Short-sprint intervals followed by immediate reflection can allow for a much more agile and flexible implementation that incorporates lessons learned as you go.

With this approach in mind, companies can scale the previously unattainable heights of efficiency offered by PdM. New technologies have made PdM possible, and organizational changes can make it feasible—now all that remains is to make it reality.

ENDNOTES

1. Gary Wollenhaupt, "IoT slashed downtime with predictive maintenance," PTC, http://www.ptc.com/product-lifecycle-report/iot-slashes-downtime-with-predictive-maintenance, accessed March 7, 2017.
2. IndustryWeek and Emerson, "How manufacturers achieve top quartile performance," WSJ Custom Studios, http://partners.wsj.com/emerson/unlocking-performance/how-manufacturers-can-achieve-top-quartile-performance/, accessed March 7, 2017.
3. Jonathan Holdowsky et al., *What is the Internet of Things? A primer on the technologies building the Internet of Things*, Deloitte University Press, August 21, 2015, https://dupress.deloitte.com/dup-us-en/focus/internet-of-things/iot-primer-iot-technologies-applications.html.
4. A. Van Horenbee and Liliane Pintelon, "A dynamic perspective on maintenance policy for complex multi-component systems," *Reliability Engineering and Systems Safety 120* (2013): pp. 39–50.
5. In a recent survey by Plant Engineering, 61 percent of maintenance professionals responded that they operate a run-to-failure method. Source: C.T. Lam and R.H. Yeh, "Optimal maintenance-policies for deteriorating systems under various maintenance strategies" *IEEE Transactions on Reliability* 43, no. 3 (1994): pp. 423–30.
6. Brenna Sniderman, Monika Mahto, and Mark Cotteleer, *Industry 4.0 and manufacturing ecosystems: Exploring the world of connected enterprises*, Deloitte University Press, February 22, 2016, https://dupress.deloitte.com/dup-us-en/focus/industry-4-0/manufacturing-ecosystems-exploring-world-connected-enterprises.html.
7. Lam and Yeh, "Optimal maintenance-policies for deteriorating systems under various maintenance strategies."
8. Mike Gehloff, "Does moving from reactive to proactive maintenance require a change management process," *Maintenance Phoenix*, January 5, 2014, http://maintenancephoenix.com/2014/01/05/does-moving-from-reactive-to-proactive-maintenance-require-a-change-management-process/.
9. Brendan Casey, "Securing your future with proactive maintenance," *Machinery Lubrication*, February 2013, http://www.machinerylubrication.com/Read/29283/proactive-maintenance-future.
10. Sniderman, Mahto, and Cotteleer, *Industry 4.0 and manufacturing ecosystems*.
11. A. D. Telang and Amit Telang, *Comprehensive Maintenance Management: Policies, Strategies, and Options* (New Delhi: PHI Learning, 2010).
12. Adam Mussomeli, Doug Gish, and Stephen Laaper, *The rise of the digital supply network: Industry 4.0 enables the digital transformation of supply chains*, Deloitte University Press, December 1, 2016, https://dupress.deloitte.com/dup-us-en/focus/industry-4-0/digital-transformation-in-supply-chain.html.
13. Deloitte client work.
14. Sniderman, Mahto, and Cotteleer, *Industry 4.0 and manufacturing ecosystems*.
15. Van Horenbee and Pintelon, "A dynamic perspective on maintenance policy for complex multi-component systems."
16. Internal Deloitte analysis derived from work with clients.
17. Stefan Van Thienen et al., *Industry 4.0 and the chemicals industry: Catalyzing transformation through operations improvement and business growth*, Deloitte University Press, June 7, 2016, https://dupress.deloitte.com/dup-us-en/focus/industry-4-0/chemicals-industry-value-chain.html.

18. Ibid.

19. Matthew Finnegan, "Trenitalia to cut train maintenance costs with SAP IoT and big data project," *Computer World UK*, October 4, 2016.

20. Nathan Nuttall, "Trenitalia drives cost savings using IoT on train operations," *Gartner*, December 2016.

21. Mussomeli, Gish, and Laaper, *The rise of the digital supply network*.

22. Jacob LaRiviere et al., "Where predictive analytics is having the biggest impact," *Harvard Business Review*, May 25, 2016.

23. The American Society for Quality considers both repair costs and the costs of poor-quality or defective products (warranty claims, returns complaints, etc.) to be costs of external failure. For more information, see American Society for Quality, "Cost of quality (COQ)," http://asq.org/learn-about-quality/cost-of-quality/overview/overview.html, excerpted from Grace L. Duffy, *The ASQ Quality Improvement Pocket Guide: Basic History, Concepts, Tools, and Relationships* (ASQ Quality Press, 2013), pp. 62–65.

24. Xiaoning Jin et al., "The present status and future growth of maintenance in US manufacturing: Results from a pilot survey," *Manufacturing Review* 3 (2016): p. 10.

25. Tom Raftery, "Italy's train operator invests big in IoT," *Tom Raftery's Internet of Things*, October 11, 2016, https://tomraftery.com/2016/10/11/italys-train-operator-invests-big-in-iot/.

26. H. James Wilson, Sharad Sachdev, Allan Alter, "How companies are using machine learning to get faster and more efficient," H*arvard Business Review*, May 3, 2016, https://hbr.org/2016/05/how-companies-are-using-machine-learning-to-get-faster-and-more-efficient.

27. See this sample dashboard and solution stack from Microsoft as just one example of many available on the market today: Microsoft, "Predictive maintenance preconfigured solution overview," April 25, 2017, https://docs.microsoft.com/en-us/azure/iot-suite/iot-suite-predictive-overview.

28. Dave LeClair, "The edge of computing: It's not all about the cloud," *Wired Innovation Insights*, July 22, 2014, http://insights.wired.com/profiles/blogs/the-edge-of-computing-it-s-not-all-about-the-cloud#axzz4ZFqo7srQ.

29. Nelson Kunkel et al., "Augmented and virtual reality go to work: Seeing business through a different lens," *Tech Trends 2016*, Deloitte University Press, February 24, 2016, https://dupress.deloitte.com/dup-us-en/focus/tech-trends/2016/augmented-and-virtual-reality.html.

30. Jin et al., "The present status and future growth of maintenance in US manufacturing."

31. Irfan Saif, Sean Peasley, and Arun Perinkolam, "Safeguarding the Internet of Things: Begin secure, vigilant, and resilient in the connected age," *Deloitte Review* 17, Deloitte University Press, July 27, 2015, https://dupress.deloitte.com/dup-us-en/deloitte-review/issue-17/internet-of-things-data-security-and-privacy.html.

32. R. K. Mobley, *An Introduction to Predictive Maintenance*, 2nd ed. (New York: Butterworth Heinemann, 2002).

33. Saif, Peasley, and Perinkolam, "Safeguarding the Internet of Things."

34. HCL, "Best-in-class service experience with predictive maintenance analytics," https://www.hcltech.com/success-story/internet-things/best-class-service-experience-predictive-maintenance-analytics, accessed April 26, 2017.

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