Predictive Maintenance: A Paradigm Shift

Using embedded sensor data for operation & downtime management

Executive Summary

One of the keys to cost-effective and efficient operations for any business with a significant number of mechanical systems is its maintenance program. Programs vary widely depending on investment profile, but all have the singular objective of maximizing uptime and making operations as cost-effective as possible.

Many equipment providers are embracing the Internet of Things (IoT) by using sensors with their products. The marriage of these closely connected data sources, characterization of the host device, and analytics predicting operational behavior has moved maintenance to a new level. This paper explores the state of the art and offers examples of companies that are taking advantage of this paradigm shift and effectively using predictive maintenance.

Preventative & Predictive Maintenance Today

It is sometimes tempting to view maintenance as an expense that does not contribute to the bottom line. The idea is “Run it until it drops” or “If it isn’t broken, don’t fix it”. Some companies have minimized programs, avoiding maintenance cost and limiting expense, only to suffer a catastrophic but avoidable failure that devastates business continuity.

Mechanical systems will experience failure at rates that are directly proportional to system complexity: the higher the complexity (especially the number of moving or parts prone to wear), the greater the number of failures. Depending on the system and the type of failure, there can be a cascading effect where failure damages connected components or adjacent systems. Remediation for these cascading failure events can be expensive and time-consuming, and the loss of production further compounds the business impact. The primary objective of predictive maintenance is to detect and repair the failing component **before** widespread impact occurs, avoiding downtime.

Some routine / preventative maintenance activities are unavoidable. Examples include replenishing consumables like lubricants or actions that are activity-dependent like tightening belts. Actual requirements can vary from the recommended schedule and present avoidable interruptions. Indeed, not all routine maintenance requires downtime. However, because of personnel safety or the nature of the operation, some planned downtime is necessary but can be performed in a period that limits overall business impact. Historically, there has always been the temptation to delay “non-critical” service sessions to a more opportune time, a time that often never exists.

One of the principal tools in maintenance has always been the human element and the process of inspection: Does anything “seem” abnormal…sight, sound, smell, or even the feel of vibrations? While inspection can be effective, reliance on the inspector does not scale efficiently or quickly, especially in today’s rapidly changing business world where agility is such a sought after capability. Both training and experience are required to enable inspectors to recognize situations that need attention. Seasoned personnel can become quite proficient once a system is well understood, but there will always be a subjective element. Additionally, even to the experts, many failures become noticeable only after the onset of the failure, which provides limited opportunity for repair.

Through the evolution of modern machinery, practitioners have realized they can obtain insight into operational efficiency by measuring many of the same operational behavior and characteristics obtained through inspection (as well as others shown in Table 1). Such measurement also provides some ability to forecast failure and avoid cascading catastrophic events. To this end, a variety of sophisticated tools and instruments has been developed and added to many operations.

TABLE 1: COMMON PREDICTIVE TECHNOLOGY APPLICATIONS

Technologies	Applications	Pumps	Electric Motors	Diesel Generators	Condensers	Heavy Equipment/ Cranes	Circuit Breakers	Valves	Heat Exchangers	Electrical Systems	Transformers	Tanks, Piping
Vibration Monitoring/Analysis		X	X	X		X						
Lubricant, Fuel Analysis		X	X	X		X					X	
Wear Particle Analysis		X	X	X		X						
Bearing, Temperature/Analysis		X	X	X		X						
Performance Monitoring		X	X	X	X				X		X	
Ultrasonic Noise Detection		X	X	X	X			X	X		X	
Ultrasonic Flow		X			X			X	X			
Infrared Thermography		X	X	X	X	X	X	X	X	X	X	
Non-destructive Testing (Thickness)					X				X			X
Visual Inspection		X	X	X	X	X	X	X	X	X	X	X
Insulation Resistance			X	X			X			X	X	
Motor Current Signature Analysis			X									
Motor Circuit Analysis			X				X			X		
Polarization Index			X	X						X		
Electrical Monitoring										X	X	

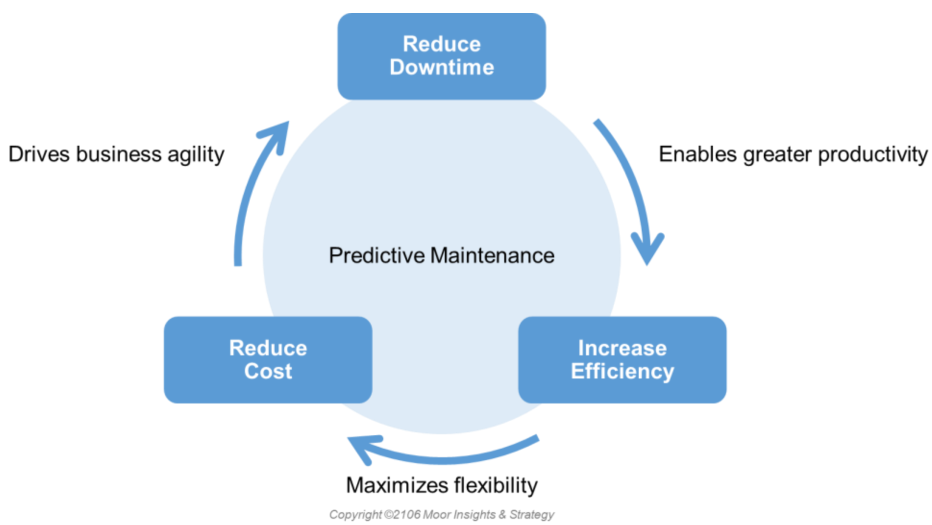
(Source: US Department of Energy Operations & Maintenance Best Practices)

One external method of fault detection is to use a forward-looking infrared imaging camera to produce infrared thermography showing “hot spots”. By comparison with previous readings, one can see the trend of increasing temperature, but it is difficult to correlate this data directly with a time-to-failure. Failure correlations is one of the difficulties encountered with all external measurement approaches. The system under test and the external measurement instruments are completely independent. As such, the relationship between the instrument readings and the normal or abnormal system operations must be established. Further, data frameworks themselves and the information needed to predict downtime for most businesses exist in silos or completely customized solutions. There has been success with this type of trend analysis, but most solutions detect change from what has been deemed the norm. It is difficult to reach the ultimate goal: alerts of impending trouble, information about the nature of the problem, and an indication of the time remaining to affect remediation.

SHIFT TO MORE EFFECTIVE PREDICTIVE MAINTENANCE

The shift to more effective predictive maintenance is driven by three key factors: the need to **reduce downtime**, the need to **reduce cost**, and the need to **increase efficiency**. These three factors drive each other in a circular manner (Figure1). As they continue to tighten the spiral, they drive better outcomes for the business.

FIGURE 1: THE PREDICTIVE MAINTENACE CYCLE



(Source: Moor Insights & Strategy)

Reducing machine downtime increases overall worker utilization, which results in higher productivity per hour, which pushes up efficiency. More efficiency delivers more flexibility for the business, as changes have lower impact due to high efficiency. That ability to move faster ultimately reduces cost as the business becomes more agile. This agility help the business reinvest in technologies that can reduce downtime, continuing the next rotation around the predictive maintenance cycle.

If a business needs to experience a failure before action can be taken, then the maintenance must lag, even if resources are forward-positioned to take immediate action. By moving from a reactive state to a proactive state, an enterprise can drive truly differentiated business outcomes through predictive analysis of instrumented systems. Even in the case of regularly scheduled maintenance, the outcomes are suboptimal, as useful life is never perfectly matched to the service schedules, and downtime, while scheduled, may not be optimized either.

With predictive maintenance, service organizations can reduce downtime by proactively monitoring and scheduling maintenance to optimize work windows. This management process enables greater productivity of assets, both human and capital. The greater productivity drives more overall efficiency in the business, which ultimately reduces both capital cost and labor cost. These savings can then be driven back into future predictive maintenance capabilities that continue the cycle, resulting in additional business benefit. Once a company begins driving savings through predictive maintenance, it has the ability to drive to the right balance of capability based on its desired savings.

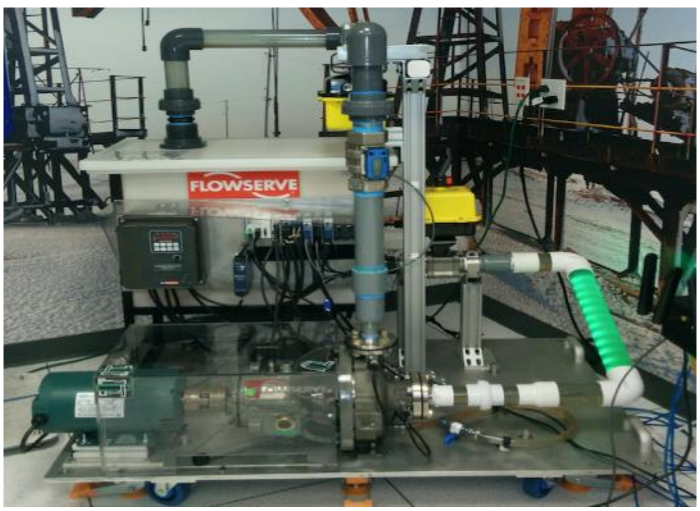
Traditionally, this type of prediction was difficult, because systems were less instrumented and the cost of processing was prohibitive. But more recently, these two dynamics have changed. More instrumented systems and lower compute costs are helping drive the enablement of predictive maintenance within the enterprise.

Over the past few generations of x86 processors, more processing capability is being enabled outside of the datacenter, which allows for more real-time monitoring and analytics to happen at the edge, closer to the systems that need to be monitored and managed. Additionally, higher bandwidth networks, along with wireless technology now enable the collection of telemetry, regardless of location. Better integration of data sources, including different types, vendors, locations, and sources enable predictive maintenance by bringing in data points that might exist outside of the physical equipment. For instance, if outdoor environmental temperature can have an impact on the service lifecycle of a component or device, then being able to pull in both ambient temperature as well as weather streams can supplement the duty cycle information to provide a more robust prediction of when the equipment will require service.

CUSTOMER CASE STUDY: FLOWSERVE CORPORATION

Flowserve Corporation, a heavy equipment manufacturer with over 245 locations worldwide, is tackling the biggest challenges in fluid motion control. Flowserve Corporation has begun to instrument its products to drive more insight for its end customers. By enabling integration into an IoT solution with Hewlett Packard Enterprise (HPE), Flowserve Corporation is able to use predictive maintenance to reduce costs and increase uptime. For its end customers in industrial fields like petroleum, where downtime can have a tremendous impact on an entire plant's overall productivity, predictive maintenance can save tens of millions of dollars per year.

FIGURE 2: PUMP WITH IOT SENSORS



(Source: Hewlett Packard Enterprise)

Flowserve Corporation has moved to a smart pump solution that uses an HPE Edgeline Converged IoT System and PTC's ThingWorx IoT platform. Together they perform local analytics using sensor data acquired by National Instruments hardware. Predictive maintenance requires close monitoring of the operational health of the equipment and also correlation across all of the past history to identify troubling trends. Because of the need for in-depth analysis in real-time and the sheer volume of data coming from the pump (10k readings per second from each of 8 sensors), an on premise solution is required, as opposed one located in a remote datacenter or the public cloud.

By locating an HPE Edgeline system near the physical equipment, be it in the facility or even in a remote location, Flowserve Corporation can enable the end customer to both monitor and analyze the data. This analysis determines the optimal time to service the equipment, minimizing the cost and productivity impact of a service event. If the system is working under capacity and still has sufficient operational life remaining before the next required service, then that event can be moved further into the future, maximizing operating cycles between events. If the system is running in conditions beyond the norm, then an accelerated service schedule may be predicted, and maintenance can be done sooner, preventing an unanticipated downtime situation.

IoT technology from National Instruments acquires telemetry data. HPE Aruba sensor beacons and networking collect and forward it to HPE Edgeline EL10/EL20 Intelligent Gateways, which act as IoT gateways / ingress points. Then the ruggedized, industrial HPE Edgeline EL1000/EL4000 Converged IoT Systems perform analytics, integrating both the IoT feed from the heavy equipment with other data such as weather, supply chain, and business operations schedules. This integrated data capability enables the customer to select the optimal time for maintenance.

When the actual maintenance is required, the system can feed telemetry data to the maintenance crew using HPE partner PTC. PTC is helping converge the physical and digital worlds by providing sensor readings, real-time status, maintenance information, and even animated service procedures. End customers can pick optimal service windows, reducing downtime. This advanced process also helps ensure accurate and speedy completion of the service when it is performed.

The business outcomes are shared by both Flowserve Corporation and its end customers. These outcomes include better customer experience, minimized downtime, maximized productivity, and more cost-effective maintenance. End customers in the petroleum refining industry face an estimated opportunity cost of unplanned downtime of as much as $20B/year in the US alone. Flowserve Corporation projects the digital telemetry data collected from pumps can reduce cost of downtime by as much as 75%.

Targeted Customer: Automotive Manufacturer

A Fortune 500 auto parts manufacturer recently deployed predictive maintenance at a pilot factory to improve asset and quality tracking. In manufacturing, maintaining stringent quality control for the output of the process is typically achieved by monitoring and tracking the raw material inputs. But inputs are only half the equation. This manufacturer expects to boost efficiency and quality not only by monitoring materials in the process, but also by monitoring the equipment. With sensors / monitoring capabilities on the programmable logic controllers (PLCs) and equipment on the shop floor, the manufacturer will track the machine quality through supervisory control and data acquisition (SCADA) interfaces securely connected to Aruba networking devices.

The collected information allows the operator to treat the equipment as raw material, predictively monitoring its status and allowing for tighter control of maintenance.

Distributed scanners assist in the asset and quality control tracking for 15 production lines, each connected to 20 remote, distributed HPE Edgeline EL10 Intelligent Gateways. These gateways are connected into the same Aruba network using roughly 300 EL10s. All input from the operators is channeled through a system of distributed touchscreen interfaces that are also tied into the Edgeline EL10 gateways. Shop environmental conditions make traditional computer interfaces difficult to maintain, but the Edgeline extended operating range make this possible.

All of this data being collected is then fed via a 10Gb connection to HPE Edgeline EL4000 Converged IoT Systems that sit on the manufacturing floor (closest to the process) running the SCADA and shop floor software in VMware virtual machines. Each EL4000 includes the HPE Storvirtual VSA hyperconverged storage product. This distributed storage solution allows not only compute, but also highly available storage to exist at the edge and in this harsh environment.

Predictive analysis will run on the EL4000 systems, enabling the manufacturer to reduce the latency in maintenance decisions, which in turn helps reduce the time to maintenance as well as the cost of maintenance. Ultimately, this solution results in higher uptime and improved productivity, as the manufacturing lines can be tweaked and tuned for optimal uptime by understanding the maintenance profiles of the underlying equipment.

By instituting this highly integrated, distributed system, the manufacturer estimates that it will deliver a $2.1M return over the next three years simply by recovering revenue lost due to downtime. This estimate does not include additional returns from efficiency improvements, better security, and more flexible operations. This new, instrumented system becomes a platform for future efficiency deployments and insight, giving the manufacturer an improved ability to control its process and outputs.

Targeted Customer: Food Manufacturer

Food preparation and packaging pose some of the most difficult regulatory challenges that exist. These processes require extreme vigilance regarding the freshness or shelf life of the material, exact knowledge of the source including transportation from upstream suppliers to actual consumption in the process, and lifecycle management of packaging to the end consumer. As the industry has matured and regulations have increased, process management has become laborious and time-consuming.

One food manufacturer is in the initial stage of streamlining the management and quality of its process and products using data. In this environment, it is important to understand each process step, the condition of the raw materials, and the state of the process equipment. By using feedback from its existing highly automated, PLC-driven process, augmented with additional sensors and trackers, this customer will be able to gain insights and affect process adjustments that previously were not possible. Each factory instance is a standalone entity that, in addition to process improvements, is able to automate and digitally eliminate the once hand-prepared but necessary paperwork. Further, the use of Microsoft Azure cloud for additional analytics is a prime example of the combination of local operational insight and global company-wide scope.

Scanners and sensors connect to Aruba IAP-325 networks, which in turn will connect to multiple remote, distributed HPE Edgeline EL10/EL20 Intelligent Gateways and five HPE EdgeLine EL1000 Converged IoT Systems. Edge analytics will provide the mechanism for immediate process adjustment and correction. Further, service technicians will be connected to operations using Bluetooth for notification and information. Because each plant is a unique situation, the exact deployment can be varied from site to site.

Using predictive maintenance, actions can be scheduled at the least impactful time, and unscheduled downtime can be avoided. In this environment, a line stoppage is not only expensive from the cost of lost opportunity, it also can result in the expense of scrapping in-flight products.

BUSINESS IMPACT SUMMARY

As more data collection is integrated into equipment and more analytics is added to operations, there is a greater correlation to the business impact and behavior of equipment, especially with regard to unplanned downtime. Each scenario examined above expects to see significant economic impact.

- **Flowserve Corporation** (US refining industry): Up to 75% reduction to estimated $20B/year downtime cost for end customers
- **Automotive Manufacturer**: $2.1M return over 3 years in recovered cost due to downtime avoidance
- **Food Manufacturer**: Significant savings due to optimization & efficiency

Actual results will likely vary, but these examples are indicative of the possible returns and opportunities enabled with this type of predictive maintenance.

HPE's Solution for Predictive Maintenance

To drive businesses toward predictive maintenance, HPE has a portfolio of products that enable its integration partners to build best-in-class solutions. HPE has a long history of predictive maintenance going back to the initial ProLiant servers of the early 1990s. Those systems included predictive monitoring that enabled the support of pre-failure alerts. As collected error data began to indicate that memory or a drive might be prone to an impending failure, replacement components were already being sent out, enabling IT to replace that component ahead of the failure and downtime. This example is one of the earliest uses of computing to drive predictive maintenance.

Enabling predictive maintenance requires compute to move closer to the equipment that must be monitored, so businesses can derive insight faster, as proximity helps reduce latency. Additionally, keeping the data local boosts security versus transmitting it to a cloud-based analysis platform. Maintaining the data in close proximity to the actual equipment can help keep communications / data transport costs in check. Considering the number of instrumented systems in modern airplanes, gigabytes of data need to be analyzed upon landing. That data cannot be sent back to the airline's HQ for analysis; analysis needs to happen as close to the plane as possible. To solve the problem of large amounts of data in remote locations, a different type of compute is required.

HPE Edgeline systems are specifically engineered to operate outside of the datacenter where there is less control over environmental conditions. The HPE Edgeline EL1000 and EL4000 Converged IoT Systems bring high levels of compute power, enabling IT to match the exact processing and environmental requirements of industrial equipment. The HPE Edgeline EL10 and EL20 Intelligent Gateways provide IoT gateway services, enabling the collection and trafficking of telemetry, health, and other data that can come both from monitored equipment as well as outside sources.

HPE Aruba delivers the networking equipment (wired and wireless) that will be required at the edge to drive the data required to foresee optimal maintenance requirements accurately. Aruba beacons enable the instrumentation of industrial equipment, taking both analog and digital information that is required to make the jump between Operation Technology (OT) and Information Technology (IT). Aruba Clearpass software helps secure access to the system by delivering security that is context aware.

HPE has partnerships with other leaders in the analytics industry, supporting the key applications for businesses to enable predictive maintenance.

Through its Global IoT Innovation Labs, HPE is working with businesses to help visualize the challenges they face as they move towards predictive maintenance, filling in the gaps and providing the components needed to move to a fully predictive future.

THE FUTURE OF PREDICTIVE MAINTENANCE

Moor Insights & Strategy (MI&S) believes that the inclusion of embedded IoT sensors in various equipment and associated systems, the endless supply of resulting data, and the ability to perform local data analytics will change many industries and create a new industrial revolution. As technology matures and standards develop, MI&S expects even greater insight will be provided directly from the machinery itself. For example, equipment will be able to render information directly, as shown in Figure 3.

FIGURE 3: HYPOTHETICAL MAINTENANCE ALERT

IMPORTANT INFORMATION: PLEASE REPLACE

Pump Identifier	**SN 20160801-3234526**
Location	**Process Line 1A**
Indication	**Main Bearing Out of Tolerance**
Based on Usage	**Predict Failure in 71 Hours**

(Source: Moor Insights & Strategy)

Open standards for machine-to-machine messaging are needed to facilitate this type of information exchange at the system level. As the machine environment evolves, standards will ease integration of new and different types of equipment into frameworks and will speed time-to-solution. The shift to more machine-to-machine communication requires some form of standardized nomenclature or structure of the data, if we are to see true interoperability.

Using data obtained directly from machinery, augmented reality (AR) will also revolutionize safety, repair, and downtime. Figure 4 shows a hypothetical example of a repair scenario with and without AR.

Few areas will experience the impact of technology more than integrated data collection and edge computing for efficiency optimization or process / machine management. This paradigm represents some of the more effective possible uses of IoT and its ability to impact business.

FIGURE 4: NORMAL MACHINE ROOM (LEFT), WITH AR VISOR (RIGHT)

(Sources: [Public domain]() and Moor Insights & Strategy)

CONCLUSION

For years, businesses have attempted to optimize maintenance by trying to understand, in hindsight, what was driving costs and what could shorten the time between incident and resolution. But this process is less than perfect. It often results in unanticipated downtime and costs when equipment state cannot be discerned accurately.

Today, more equipment can be monitored in real-time, and compute solutions can be moved closer to the edge, enabling a business to turn its sights to the prediction of events and requirements instead of relying on a reactive model. By moving compute closer to the edge and enabling IoT analytics closer to the equipment, a business can better match its maintenance to the actual needs of the equipment, reducing downtime, boosting productivity, and strengthening the bottom line.

As businesses move in this direction, MI&S believes that HPE has created a portfolio of products—complemented by partnerships with key technology providers—that enable a business to take the next step into the realm of predictive maintenance. Starting with its HPE Edgeline Systems and running all the way through the Aruba and Vertica products, HPE intends to help IT bridge the gap between OT and IT, leveraging the latest compute intelligence to drive predictive operational capability.

IMPORTANT INFORMATION ABOUT THIS PAPER

AUTHOR
John Fruehe, Senior Analyst at Moor Insights & Strategy
Jimmy Pike, Technologist in Residence at Moor Insights & Strategy

EDITOR
Scott McCutcheon, Director of Research at Moor Insights & Strategy

PUBLISHER
Patrick Moorhead, President & Principal Analyst at Moor Insights & Strategy

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