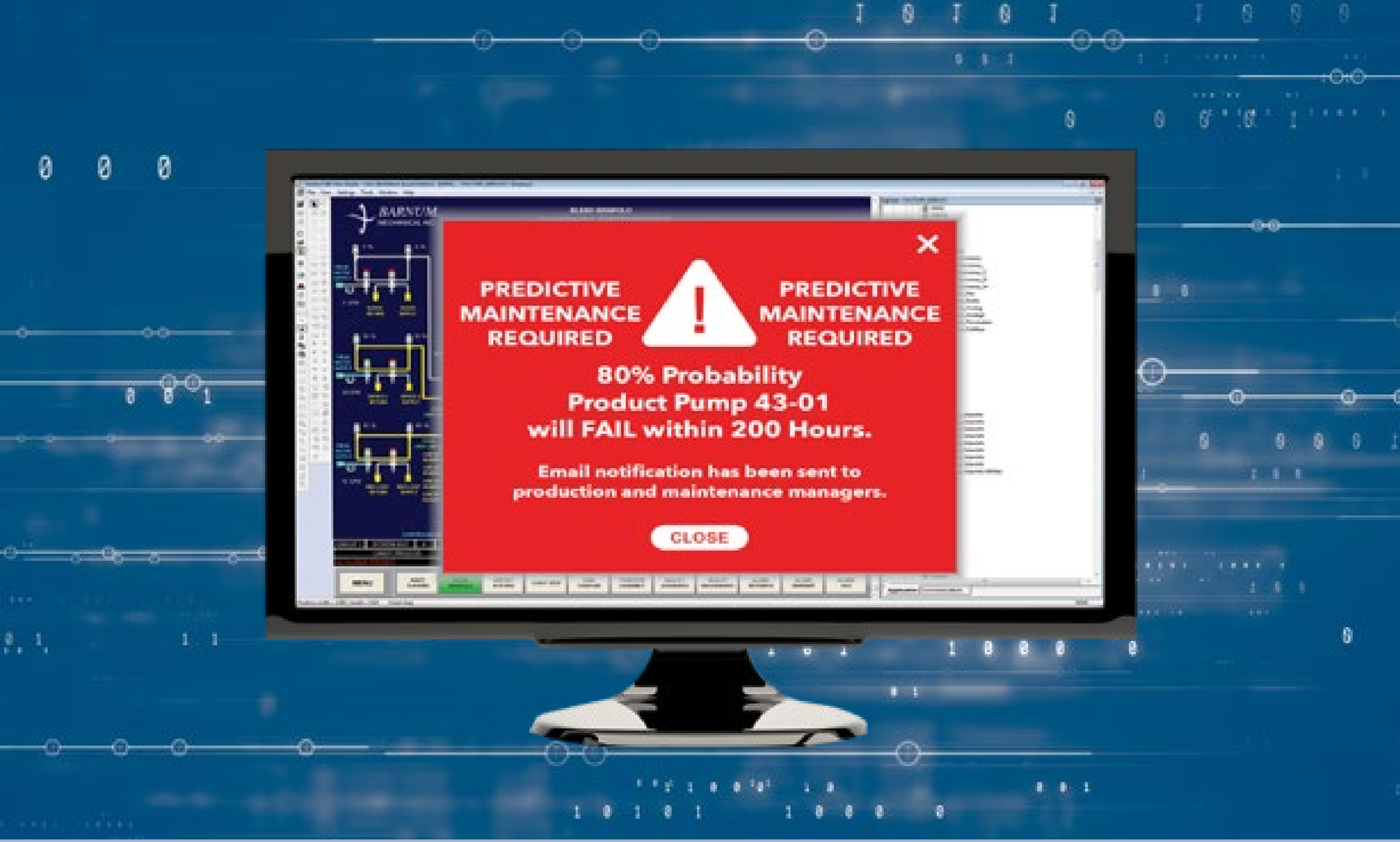


Delivering Uptime with a Predictive Maintenance System

WHITE PAPER

BARNUM MECHANICAL INC

40 YEAR ANNIVERSARY 2020

Delivering Uptime with a Predictive Maintenance System

Predictive Maintenance

Many food and beverage (F&B) processors use condition-based maintenance (CBM) systems to manage maintenance and repairs. CBM systems react to real-time events when process variables reach predefined set points. Sensors detect that the set point has been reached and trigger an alert that maintenance should be performed. Preventative and condition- based maintenance has the benefit of planning and reducing unexpected downtime however, it always results in over-maintenance or under-maintenance on any given machine.

Today as much as one-third of U.S. F&B processors are moving to Predictive Maintenance (PdM) systems to increase uptime. PdM systems rely on complex computer modeling to predict when a machine will need maintenance before the setpoint is reached and before a failure occurs. PdM systems take maintenance to the next level— improving operational performance by narrowing the gap between required maintenance and actual machine failure. Research has shown that between 35 – 50 percent of all time-based preventive maintenance tasks can be eliminated by using PdM.[1] PdM allows maintenance to be performed when it is least disruptive and most cost effective, while ensuring that production equipment doesn't fall below set performance, quality, or safety standards.

Asset management is critical in processing where advanced machinery is expensive, and depreciation is a major cost. Major cost savings can be achieved by moving to predictive maintenance systems. The initial investment can be high but adopting a long- term predictive maintenance system is a cost-efficient strategy, contributing to a significant decrease of maintenance hours and spare parts expenses, and to an increase in production performance.

[1] McKinsey Global Institute, The Age of Analytics: Competing in a Data-Driven World (Dec 2016) and The U. S. Department of Energy's Operations and Maintenance Best Practices.

How predictive maintenance (PdM) works

PdM systems are not an out-of-box or one-size-fits-all solution. Rather, they are uniquely designed for the identified critical assets in any given process. PdM requires real time monitoring of equipment, robots, and support systems. PdM works by:

1. Sensors monitor and detect information such as anomalies and over or under key performance indicators (KPIs)
2. Sensors transmit the information (data) via a SCADA historian to PdM software
3. The PdM software analyzes the data and predicts probable machine / system failures

PdM systems identify conditions which can't be detected by output or visual inspection alone. The systems rely on advanced diagnostic and sensing technologies for machine condition monitoring which measure such things as:

- Temperature
- Pressure
- Vibration
- Moisture levels
- Rotation speeds
- Amperage Draw
- Radiation

By detecting above or below normal values, the sensors signal potential failure conditions such as:

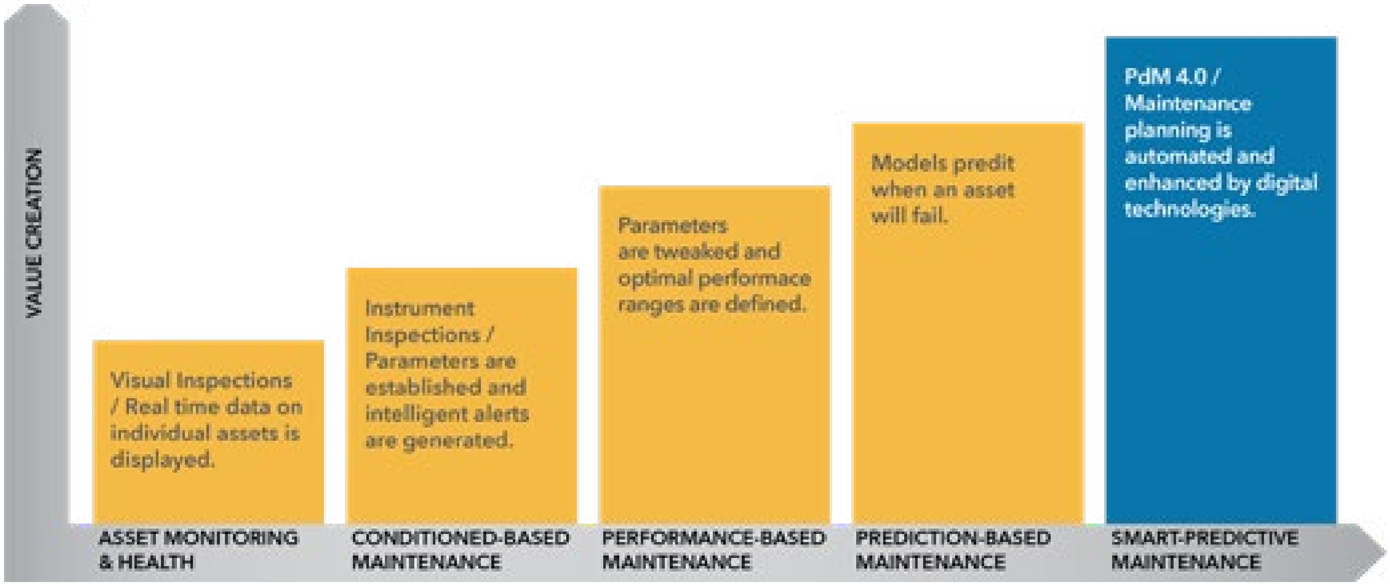
- Increased temperatures may lead to components melting or burning
- High vibration could indicate a centrifuge is out of balance
- Excess current draw could indicate worn or damaged bearings, or bent blades

The PdM analytics software which predicts failures uses complex machine-learning algorithms, time series analysis and regression analysis. This data, which forms the basis for the PdM, can be culled from a combination of the processor's maintenance records as well as aggregated failure data provided by the equipment manufacturer.

The algorithms are self-learning and infer rules by performing trials on test data and constructing failure models. When a PdM system has been successfully implemented, it makes real-time decisions and maintenance is only performed on machines when required and at the lowest possible frequency.

The PdM system algorithms also inform users of the specific maintenance tasks which need to be performed. One of the key benefits of PdM systems is the ability to draw from a library of information to identify what has broken or what needs to be replaced.

Evolving to PdM 4.0 / Smart Predictive Maintenance



Condition-based monitoring and the Industrial Internet of Things

Condition-monitoring tools such as vibration sensors and thermal imaging sensors, are a key component of PdM. The sensors monitor the health of machines and processes, and constantly pass the data to the analytic software. The software parses the information and highlights deviations from the norm on the software dashboard(s) or sends alarms, if necessary.

The monitoring sensors must contain computing devices which enable them to be programmed and to wirelessly send and receive data via the internet. The automated communication between the sensors (things) and the internet is referred to as the Industrial Internet of Things (IIoT). PdM requires an IIoT backbone to connect your machines to your data center and to facilitate the collection and distribution of sensor and other data.

The power of collaboration

Predicting failure for a specific machine is a challenge beyond the scope of condition monitoring equipment, as a broader sample of benchmarking on similar equipment is needed for reliable prediction.

Some Original Equipment Manufacturers (OEMs) are taking an active role in ensuring their devices and equipment can not only provide the sensor or machine data for your process, but also provide historical data compiled from other user's equipment failures. The compiled data can be fed into your PdM software to help your system learn.

Some OEMs provide the device "health" data for free or offer paid services to monitor machine/device health data and predict when you need to change parts, make adjustments, or perform some other maintenance activity.

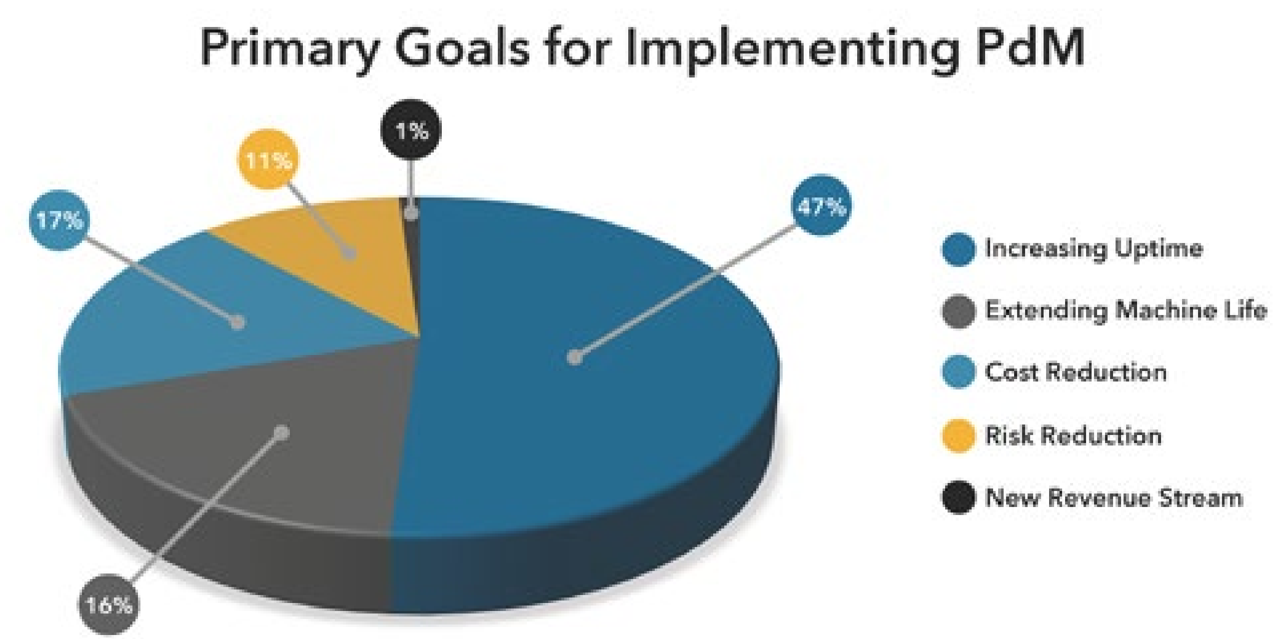
Types of Data

The types of data used for PdM are:

- Condition of machine or equipment
- Usage of the machine or equipment
- Maintenance history
- Condition data and maintenance history of similar machine or equipment within the company
- Condition data and maintenance history of similar machine or equipment from other companies (generally provided by OEM)
- Environmental data (heat, moisture, noise)
- Process data (changes to the process or recipe)

Why Companies are Adopting PdM

One in three manufacturing companies are adopting some form of PdM system. According to a in depth study[2] of 280 companies, here are the reasons why:



[2] PcW and Mainnovation's Predictive Maintenance 4.0, Predict the unpredictable, 2019.

The Evolution of PdM

According to IBM's Vienna Development Method (VDM) methodology, companies need to develop capabilities in five domains to increase their PdM maturity and realize the financial benefits. The five domains are:

- Processes: Design and implement work processes that drive maintenance to the next maturity level
- Content: Ensure the required data is available
- Performance Measurement: Monitor and tie asset performance to meet business objectives
- OT/IT: Install the needed OT/IT infrastructure
- Organization: Ensure the organizational structure supports the cultural shift to the next maturity level (skills, capabilities, incentives)

Capability / Domains	Visual Inspections	Instrument Inspections	Real Time Condition Monitoring	PdM 4.0
Processes	• periodic physical inspection • checklists • paper records	• periodic physical inspection • instruments • digital recordings	• continuous real time remote monitoring • sensors • digital recording	• continuous real time remote monitoring • sensors and other data • digital recording
Content	• paper-based reports • multiple inspection points	• digital condition data • single inspection points	• digital condition data • multiple inspection points	• digital condition data • multiple inspection points • digital environment data • digital maintenance history
Performance Measurement	• visual inspection • paper-based trend analysis • prediction by expert opinion	• automatic norm verification • digital trend analysis • prediction by expert opinion	• automatic norm verification • digital trend analysis • monitoring by CM software	• automatic norm verification • digital trend analysis • prediction by PdM software • advanced decision support
Infrastructure	• MS Excel /Access	• embedded instrument software	• condition monitoring software • condition database	• condition monitoring software • big data platform • Wi-Fi network (IIoT) • statistical software
Organization	• experienced craftsmen	• trained inspectors	• reliability engineers	• reliability engineers • data scientists

Chart reprinted with permission from Manniovation.

Benefits of PdM

The key benefit of implementing a PdM system is increased profits. Other benefits include:

- Minimize or eliminate unscheduled downtime
- Lower product waste
- Higher product quality
- Reduced energy usage
- Reduced safety risk
- Reduced environmental impact

The world-renown McKinsey Global Institute produced a comprehensive study on the potential of using industrial analytics to reduce expenses, The Age of Analytics: Competing in a Data-Driven World. The broad-ranging study found that PdM systems substantially improve machine uptime and overall performance.

Here are some of their key findings:

- 30-50% reduction in downtime due to equipment failures
- 10-40% reduction in maintenance costs
- 3-5% increased machine useful life
- 10-25% reduction in worker injuries
- 10-20% reduced waste

The challenges of implementing PdM and critical success factors

The primary challenges and success factors to implementing a PdM systems are:

1. Budget
2. Buy-in / culture shift
3. Technology implementation
4. Training
5. Big data & data security

#1 Budget
Developing a realistic cost-benefit analysis for your organization and getting approval for the funding is a big hurdle for most organizations. The primarily costs include:

- New infrastructure
  - Sensors and other monitoring devices
  - Wireless equipment
  - Electrical wiring
  - Cloud-based processing and data storage
  - Data security
  - PdM software
  - Additional equipment such as tablets or other handheld devices

- Operational changes
  - Establishment of the implementation team
    and team meetings
  - Role changes within the maintenance department
  - New functions (such as data analytics)
  - Procedures and process changes for evolving from preventative to predictive maintenance

- Special expertise
  - PdM software
  - Identifying critical processes, machines and spare parts
  - Establishing, measuring and reporting KPIs benchmarks and targets
  - Maintaining new monitoring and sensor equipment
  - Data entry and human-to- machine interface (HMI)
- Training

#2 Buy-in / culture shift
Creating a cultural shift which embraces PdM and prioritizes the required time is the second hurdle. The real value of a maintenance department is to deliver process uptime. In many organizations, maintenance is viewed as an expense rather than a role which if performed well, directly contributes to profit.

Implementing an effective PdM system requires more than time and money– it requires a cultural shift and change management skills which go beyond the maintenance department. Implementing a PdM system requires buy-in at every level of the organization, from the CFO who frees up the funding and helps analyze the results, to the maintenance personnel who maintain the equipment and work within the new system.

#3 Technology Installation and Implementation of Infrastructure, Equipment and Software
The installation of new infrastructure, equipment, software, and new processes and procedures will be a team effort. The PdM integrator will work closely with all functional departments associated with your manufacturing process.

#4 Training
Training will require cross-functional cooperation between maintenance, process engineering, OT, quality personnel, production personnel, finance and even purchasing.

#5 Availability of Big Data
The biggest barrier to adopting a PdM system may be in interpreting the data and extracting value from the analytics, and then incorporating data-driven insights into standard business processes.

The real value of a maintenance department is to deliver process uptime.

PdM systems collect data on temperature, humidity, speed, vibrations, thermal imaging and other KPIs. This data is constantly sampled and transmitted, creating mountains of data. The data is compiled and fed into self-learning algorithms. Each time new data is received, the system learns more and becomes more effective at predicting problems. And each time, the mountain grows. *Data is a key company asset, but its value is tied to its ultimate use.*

A selective approach must be taken to data collection as over-archiving muddles the value of the information. Data filtering is essential to ensure focus on a limited number of variables. Collecting data does not move an organization closer to PdM— the value is in revealing changes over time and tying those changes to machine and process problems.

Industry Challenges for Food & Beverage

F&B equipment is especially complex and tough to maintain due to the interconnected conveyors, belts and other moving equipment. Sanitary processing creates wet environments, which can easily damage key equipment, switches and electrical components. And chemical exposure, temperature extremes and CIP all contribute to premature machine failures.

F&B processors are sometimes slow to adopt new technologies as they must overcome unique processing and maintenance obstacles related to sanitary regulations and safety. This can make plant managers hesitant to implement PdM systems, especially when preventive maintenance routines seem to work well enough. But drops in hardware costs and software tools, and the proven benefits that PdM technologies have already delivered, are pressuring F&B processors to take their maintenance procedures to the next level.

The Food Safety Modernization Act (FSMA), has shifted the emphasis from monitoring to preventive controls. Processors are held to the high a standard for preventing contamination by identifying problems before they occur. PdM systems support FSMA and Current Good Manufacturing Practices (cGMP) and helps production and maintenance personnel proactively address issues and maintain consistent product quality.

Studies show that equipment age at more than half of America's F&B food processing plants exceeds 20 years.[3] With aging equipment, stringent safety standards and regulatory emphasis on prevention, it's clear that processing equipment maintenance is more important than ever. The key question is how to cost-effectively implement PdM.

Markets and Markets, a leading B2B company, reports that manufacturers will spend $74.8 billion per year on smart factory technology by 2020 and the McKinsey Global Institute estimates that the total economic impact of smart factories could reach $3.7 trillion per year by 2025.

[3] Advanced Technology Services, Inc., What to Know About Predictive Maintenance and Food Processing, 2019.

Basic Requirements for a PdM System

The basic requirements include:

- IIoT-enabled sensors and monitoring equipment
- IIoT backbone
- Cloud computing and storage space
- SCADA data historian
- PdM interface software

Supervisory Control and Data Acquisition (SCADA)

SCADA systems are used to monitor and control processing equipment and are widely used in F&B plants. Some processors do not have comprehensive SCADA systems but still employ standalone monitoring systems for key equipment.

PdM systems rely on SCADA systems to:

- Monitor real-time conditions
- Record a history of conditions and events (historian)
- Aggregate the data
- Use machine-learning algorithms, time series analysis and regression analysis to analyze the data and predict failures
- Report on the conditions and events

Implementing a comprehensive PdM system requires software integration between your machines, equipment, your SCADA historian, and specialized PdM software. There are several ways to deploy the PdM software and your company expertise will drive the decision of which is the best for you.

The three main deployment methods are:

1. Build your own software and integrate it into your existing SCADA system

2. Buy a packaged Computerized Maintenance Management System (CMMS) and integrate it to your SCADA system

3. Use your existing process automation and controls provider to create a custom solution based on your existing equipment and SCADA system

Examining the options

1. Building your own software
   Building an in-house solution leveraging open source libraries may be the best solution for companies who employ data scientists and software programmers. They (presumably) know your process well and understand what is important to your organization.

2. Buying a Computerized Maintenance Management System (CMMS)
   There are many companies specializing in selling and implementing cloud-based CMMS to manage your condition-based monitoring and PdM system. These off the shelf systems are specifically designed to establish and follow PdM routines as well as:
   - Record, track and analyze conditions and maintenance events
   - Send alerts when maintenance is recommended
   - Automatically order replacement parts
   - Monitor equipment inventory

A key factor when considering a CMMS is finding a vendor with experience in F&B and processing equipment.

3. Using your existing automation and controls company
   Chances are you already have some form of automated control system. With today's open software platforms anyone can integrate a PdM module into your existing SCADA system, but there are significant advantages to using your existing automation and controls provider. Your existing provider:

- Is an expert in F&B processing
- Is an expert in F&B controls and automation
- Understands compliance and food safety regulations
- Is familiar with your process
- Knows your machines, equipment, and their specs
- Designed your existing SCADA system and is best positioned to integrate a new PdM module
- Can build a module which communicates with your existing PLCs and IT/OT systems
- Can custom design your software layers and dashboards

A High-Level Implementation Plan

There are many ways to implement a PdM system. Some companies invest a lot of time and energy in the planning stages and rollout a comprehensive system all at once, while others start small and implement PdM on specific high-risk non-redundant machines and then add more machines over time.

There are 12 steps to implementation:

1. Organizational alignment
2. Mapping your existing infrastructure and equipment
3. Collecting Available Data
4. Asset valuing
5. Reliability monitoring
6. Determining your new infrastructure and equipment needs
7. Installing the hardware
8. Algorithm design
9. Installing, programming and integrating the software
10. Algorithm optimization
11. Creating new processes and procedures
12. Training

Note: These steps are generally sequential, but many steps may be run in parallel. For example, training is listed as the last step. In reality, training on PdM may be one of the first steps for the project team and different aspects of the training such as feedback loops and continuous improvement will be ongoing.

1. Organizational alignment
   A project management team must over see all aspects of the implementation and ensure the organization is set up to support the project.

2. Mapping your existing infrastructure and equipment
   You'll need a map of your existing process and your infrastructure including all machines, equipment, utilities, (including IIoT backbone)
   software and hardware. Data collection points must be identified.

3. Collecting Available Data
   All available maintenance data and machine / equipment health data must be compiled for analysis.

4. Asset valuing
   In this step you'll identify and rank assets for which it is feasible and worthwhile to use PdM techniques. This is generally limited to high-critical to medium-critical equipment.

5. Reliability monitoring
   Once you have identified and ranked your assets for PdM, use root cause analysis (RCA) and failure mode effects analysis (FMEA) to determine what data you need to collect. You will also set maintenance benchmarks and failure KPIs such as machine tolerances and limits.

6. Determining your new infrastructure and equipment needs
   When you've mapped your system and ranked your assets, you can determine which new sensors and equipment you need to perform the real time performance monitoring. You may also need new equipment to support wireless communication between the process equipment, the data center and the PdM software.

7. Installing the hardware
   In this step your new monitoring equipment and infrastructure equipment is installed and tested.

8. Algorithm design
   This step is usually performed by a data scientist or engineer who constructs self-learning algorithms to predict failures.

9. Installing, programming and integrating the software
   This step is usually performed by a data scientist or engineer who will oversee the implementation of the new software and develop the dashboards, reports and information access points for maintenance personnel.

10. Algorithm optimization
    This is not so much a step in the implementation process but an ongoing process of analyzing the data and optimizing the PdM performance.

11. Creating new processes and procedures
    New processes and procedures must be developed to support the PdM system and the company objectives. For example, procedures must be changed from "routine maintenance" to "necessary maintenance" which has been identified by the system.

12. Training
    Training will require cross-functional cooperation between maintenance, process engineering, quality assurance personnel, production personnel, finance and even purchasing.
    The training should include:
    - Using the analytical capabilities of the software
    - Using the new software dashboards, alerts and reports
    - Maintaining the new monitoring sensors and other equipment
    - New processes and procedures
    - Feedback loops and continuous improvement

Evolving to PdM 4.0

Barnum Mechanical has designed and installed hundreds of automated process systems and network architectures. Our systems automation engineering team is the right partner to guide your organization through the evolution from preventative or conditioned-based maintenance to PdM 4.0. And we can do it using your existing equipment and SCADA system. The evolution to PdM 4.0 requires organizational commitment, focus and change management. We can help.

How BMI used PdM techniques to extend processing time for a beverage manufacturer.

Our customer had a Thermal Process System with a plate surface heat exchanger that had been processing sports drinks and juices for approximately fifteen years. Last year they decided to start processing a new tea product and almost immediately they experienced critical process alarms such as differential pressure, low product temperature, and high and low flow.

The alarm conditions subsided after a CIP, but ultimately, they would return after x amount of run time. The CIP did create a temporary fix, but they were becoming more frequent and the shutdowns were unscheduled and happening because of a critical alarm that caused product loss.

Because process loops are so closely related, it is typical for thermal processing system to see multiple process variables reacting when there is a single problem. When BMI inspected, we found the problem to be excess fouling on the heat exchanger's plate surfaces and we concluded that the new tea product had a higher concentration of tannins which were adhering to the plates at high temperatures.

When the fouling began to occur, the efficiency of the heat exchanger would lower, which required the heating media temperature to be increased to achieve the desired product target temperature. If the media temperature was increased too quickly, the "burn on" would occur more often.

We determined that if we lowered the approach temperature (difference between the heating media and product target temperature) that it would take longer for the fouling to start accumulating on the plates.

To increase processing times, we wrote an algorithm in the PLC to constantly adjust the media temperature setpoint to the closest approach possible, while still maintaining the desired product temperature setpoint. This method allowed the system to extend production runs between CIP, and by utilizing the available analytical data, our system was able to warn the operators in advance so that CIP could be scheduled at the optimal time. That's PdM. It works.

> We've worked with Barnum Mechanical many times over the past 5 years. They have provided us with a high-level of skill in controls and electrical engineering, instrumentation configuration and troubleshooting. Barnum has proven that they can systematically analyze a control system and fine tune the equipment until optimal performance is achieved. We value our relationship with them and will continue to rely upon them in the future.
>
> **William Piper, Vice President, Production**
> ***Gekkeikan Sake USA, Inc.***

# # #

Acronym Key

ACM – Asset Condition Management

CBM - Condition Based Monitoring

cGMP – Current Good Manufacturing Practices

CIP - Clean in Place

CM – Condition Monitoring

CMMS – Computerized Maintenance Management System

DCS - Distributed Control System

EAM – Enterprise Asset Management

ERP - Enterprise Resource Planning

F&B - Food and Beverage

FMEA – Failure Mode Effects Analysis

FSMA - Food Safety Modernization Act

GMP – Good Manufacturing Practices

HMI – Human-to-Machine Interface

IBA– Installed Base Analysis

IT – Information Technology

MVP– Minimum Viable Product

OEE – Overall Equipment Effectiveness

OT - Operational Technology

P-F Interval – Potential Failure Interval

PdM – Predictive Maintenance

PLC – Programmable Logic Controller

PM - Preventative Maintenance

RCA – Root cause analysis

SCADA – Supervisory Control and Data Acquisition (system)

VDM – Vienna Development Method

ABOUT THE AUTHOR

Doug Cornwell has been the controls engineering manager at Barnum Mechanical Inc. since 2006. He has been in the controls field specializing in food, beverage, and aseptic processes for 20 years. Doug enjoys designing and overseeing the implementation of the controls and electrical systems that bring Barnum Mechanical Inc.'s process designs to life.

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ABOUT BARNUM MECHANICAL INC.

Barnum Mechanical Inc. (BMI) is an industry leading full-service sanitary process company specializing in next generation solutions for the food, beverage, and specialty process industries. From complete design-build turnkey projects, to trouble shooting and repairs, BMI's team of design engineers, controls engineers, project managers and expert installers provide unsurpassed value and results.

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