Condition Based Monitoring

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Introduction

Jacobs provides Maintenance Services for many government and commercial clients around the world. We are responsible for maintaining millions of assets including one of a kind specialty items such as a 135,000 HP horizontal mount motor, the largest of its kind in the world. A majority of the assets we maintain have been in service for extended periods of time, in some cases more than 30 years, well beyond their anticipated lifecycle. A robust Preventive Maintenance (PM) approach is required to maintain these assets and deliver a meaningful level of reliability. However, intrusive PMs, can introduce significant risk to our customer's availability and bottom line. In addition, our customer's maintenance budgets are not typically adequate to perform all required PM work, especially when apportioning a percentage of the budget to corrective maintenance, which has much higher material and labor costs. Therefore, implementing more efficient programs that contain real-time Condition Based Monitoring (CBM) as a central focus is essential to effectively manage these challenges.

In this whitepaper, we demonstrate how Jacobs plans, implements, and sustains state-of-the-art CBM programs and how this approach can be adapted and scaled to any site

Key Capabilities

- Assessment, planning, implementation, and sustainment of a Condition Based Monitoring (CBM) program
- Integration of Operational Technologies (OT) and Information Technologies (IT) to provide a robust CBM Platform
- Specification, installation, and commissioning of OT (sensors and monitoring systems)
- Application of Data Analytics to identify changes in asset health and initiate corrective actions

Background

In 2012, Jacobs took the initiative to develop key maintenance strategies for NASA at NASA's Langley Research Center (LaRC) in Hampton, VA. Jacobs developed and proposed several innovative solutions with the overarching objective of moving the client from a long-standing frequency-based maintenance program to a modern Reliability Centered Maintenance approach, which is focus-based on real-time Condition Based Monitoring (CBM). NASA found our CBM proposal, to include the significant value in the predicted uptick in their critical systems reliability and availability compelling. Consequently, they were able to use this information to secure $14M to implement real-time condition based monitoring of critical assets and systems.

While the initial efforts to secure funding were successful, Jacobs recognized that a truly effective program would require more than simply installing a handful of CBM devices. The challenges and risks associated with a $14M investment for a CBM system were significant, making it critical for Jacobs to develop a comprehensive strategic plan that included: best practices; prioritization of CBM applications; utilization of pilot programs; selection of proper IT systems; and recognition of technology challenges such as wireless transmission and power for wireless devices, as well as determining where to house resources for collecting, evaluating, and dispositioning the constantly streaming CBM data.

Initial efforts to determine how to apply CBM

Jacobs' initial ideas were based on proven CBM approaches implemented through building automation systems at various Jacobs managed sites where condition monitoring was applied to cooling towers, air handlers, pumps, chillers, generators, and uninterruptable power supplies (UPS). The assets were interlinked primarily through BASs like Trane, Siemens and Johnson Controls using existing hardware and cabling infrastructures. We programmed limits and alarms to alert Energy Management Control System (EMCS) and Predictive Testing and Inspection (PT&I) technicians to trouble conditions. For example, differential pressure transmitters were installed across air handler filter banks to detect threshold limits and guide filter replacement frequency.   Additionally, Jacobs uses key Jacobs O&M Subject Matter Experts (SME) to provide guidance during planning, implementation and startup of new systems to ensure optimal configuration.

Documenting Best Practices

We leverage lessons learned and apply them to our client's systems in several areas, including our selection of cable type, device type, and device location. For example, we have learned that unarmored cabling used in outdoor locations is susceptible to wildlife damage and to damage from ladders and technicians stepping on them when working on the equipment. Another best practice we have learned and leveraged is selecting of force measurement devices. Specifically, we learned that two-axis accelerometers are less expensive than three-axis accelerometers, and yet two-axis accelerometers provide the same level of accuracy. We have learned that accelerometers placed on pumps and motors yield better results when mounted 45 degrees from vertical rather than mounted directly parallel to the vertical, or horizontal, axis.

Where to apply CBM

In addition to leveraging Jacobs best practices from locations such as the Air Force's Arnold Engineering Development Complex (AEDC) and NASA's Stennis Space Center (SSC), we have worked closely with industry partners and Original Equipment Manufacturers (OEMs) to identify technologies for different classes of assets. Based on this research, we developed a high-level list of technologies to consider for the condition monitoring of different asset classes. A representative list is provided in the table below.

Asset Class	Technology	Benefit
Air Handlers	Differential pressure switches and transmitters on filters	• Indicates pressure drop across filter banks potentially increasing the time between filter changes reducing material spend and avoiding unnecessary downtime.
Cooling Towers	Accelerometers on pumps and gear boxes	• Provides for real-time data collection and eliminates technician routes • Increases reliability and reduces cost of repairs as gear boxes replacements and cooling tower downtime are both costly and disruptive
Motors	Motor Insulation Quality, Motor System Performance Monitoring	• Provides for real-time data collections and eliminates technician routes • Increases reliability of critical motor systems
Online Oil Monitoring	Monitoring of oil viscosity, water content, particulate content, temperature	• Provides for real-time data collections and eliminates technician routes • Increases reliability of critical lubrication systems
UPS and Substation Battery Monitoring	UPS, and battery status and health	• Provides for real-time data collections and eliminates technician routes • Increases reliability of critical battery systems
Generator Monitoring	Generator Status and health	• Provides for real-time data collections and eliminates technician routes • Increases reliability of critical generator systems
Other Critical Systems	Leverage existing Facility Automation Systems to collect and trend data	• Infrastructure already in place to collect data • Provides the largest potential ROI due to high dollar value and revenue generation of research systems

		• Provides maintenance engineers and technicians greater insight into the historical operation of the equipment
Asset Class	**Technology**	• **Benefit**

After utilizing best practices, documenting lessons learned, and identifying systems where CBM could be applied, Jacobs employed a third party Asset Management Company to evaluate our approach. While they agreed with the approach, they validated a valuable piece of information in their report, *"CBM does not eliminate human oversight and decision making."* Following this guidance is critical for sustaining a CBM program. Having qualified Maintenance and Reliability professionals to sample and oversee asset condition data is imperative as these individuals ensure the system is appropriately executing decision logic and that the system is continuously updated with lessons learned and relevant operational information (e.g., performance threshold parameters).

Pilot Program

Leveraging our program success at various client sites and our identification of candidate systems for CBM, we utilized the Building Automation System (BAS) approach and similarly implemented it to monitor and measure remote data from field devices for our large Confidential Client. We then applied the lessons learned described above. We conducted a pilot program at a new 78,000 sf facility, by instrumenting eight (8) chilled and hot water pumps in the penthouse mechanical room. We utilized the Trane BAS to monitor vibration of inboard and outboard components of the pumps and motors, and we established an alarm set point at a velocity of 0.18 in/sec, consistent with ISO 10816, *Vibration Severity Standards*. To ensure technicians were aware that the respective equipment was part of our CBM program, we installed stickers identifying them as such. This approach ensured that our field technicians would inform our BAS operators that maintenance was being performed on a CBM asset and that a potential false alarm may trigger during the maintenance process. Additionally, the CBM identification labels provided our personnel with the appropriate situational awareness for working near sensitive CBM electronic devices and their cabling.

While we were able to validate our approach with the pilot program, we also learned new lessons, mostly related to how we measure vibration and establish set points for variable speed assets. Commissioning also needed to be performed to validate the output of the devices. This was performed by using calibrated handheld metering and test equipment. Additionally, while this monitoring approach is

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sufficient for assets where a simple alarm suffices to provide condition alerts, we realized we may be limited in our ability to collect, trend, analyze, and take action on real-time data. To adequately assess the health of an asset, we would need a real-time data collection tool (typically referred to as a Historian) and a suitable software package to evaluate the data and generate follow-up actions (typically referred to as a Rules Manager). These tools would need to interface with our other maintenance systems, such as the CMMS (Maximo).

Master Plan

After the success of the initial pilot effort we developed a CBM Master Plan, the first of its kind that we are aware for our client. The purpose of the CBM Master Plan is to provide a document that can be used by the client to understand the objectives of CBM, gain knowledge of current CBM efforts, document decision-making processes, plan CBM Capital Improvement projects, and provide guidance on the continued management of the CBM program. The intent is to address the application of CBM as it pertains to planning, design, construction, acceptance, operation, and maintenance of assets. The plan is reviewed and updated on a periodic basis to document current status of the CBM program and outline the path forward for future CBM implementation and initiatives.

CBM Data System

The CBM data system consists of a suite of software packages and servers. The two main software packages used are the **OSI PI System from OSIsoft®** and **Meridium Asset Performance Management GE Digital®.**

OSI PI System

The OSI PI System has several components tightly linked together. Its primary function is to interface with controls systems, I/O devices, and various data sources. It collects time stamped values from these sources and stores them in a data archive database (known as the Historian) designed specifically to be reliable and efficient for real-time data collection and historical data retrieval. Current interfaces allow for communication over Ethernet using Modbus, BACnet (Building Automation and Control network), OPC (Object linking and embedding for Process Control) and SNMP (Simple Network Management Protocol). The PI Data Archive is currently licensed for 7,000 data points, also known as Tags. Licenses can be expanded in the future to include additional tags and interfaces as the system expands.

The OSI Pi System:

- Can be configured for an unlimited number of monitored data points
- Supports over 830 different communications interface protocols
- System has an intuitive graphical interface, PI Vision that is accessed through a web browser utilizing specified user accounts.

Meridium Asset Performance Management

Meridium APM integrates data from the OSI PI System and the Maximo Computerized Maintenance Management System (CMMS) along with other user identified data sources. Health indicators can be created in Meridium APM that utilizes an asset's repair history and condition data. Health indicator status is used to indicate the need for further inspection of an asset's performance, or immediate need for maintenance. An analyst can review an asset's health parameters and trigger the generation of a work order, or the system can be set to automatically generate a work order. Customized dashboards can be created in Meridium APM for individual users. Meridium APM also contains data analysis tools known as Policies, and a notification system used to make notifications when health indicators change.

- Provides visibility of real-time availability and reliability of your assets
- Identifying impending failures early
- Enabling compliance with ever-expanding regulatory requirements
- Helping to optimize your assets′ performance

Identification of Projects

In addition to establishing the data system architecture, are initial efforts identified and prioritized a list of approximately 20 maintenance related projects. These projects were selected by assessing historical CMMS data, evaluating critical systems, and performing a Return on Investment (ROI) analysis for various client assets. Once prioritized, the projects represented the best ROI and largest impact to reliability. These projects included instrumenting critical cooling towers, pumps and chillers with accelerometers and equipping air handlers with accelerometers and differential pressure switches. In addition, we require that all new assets are evaluated for the application of CBM technologies.

Since the initial efforts we have continued to expand the application of vibration and differential pressure technologies to over 550 client assets. In addition, we have evaluated and added new technologies to the CBM program. These technologies include:

- **Megalert:** Online monitoring of electric motor insulation quality.
- **Online Oil Monitoring**: system to continuously monitor the oil by distinctive sensors installed in-line. Currently we are measuring five different aspects of the total quality of oil. These parameters include oil temperature, water content, Ferrous and Non-Ferrous particulates and oil ohmic resistance trended over time to allow us to better understand the depletion of oil additives.
- **Online Battery Monitoring:** system that continuously monitors industrial and telecommunication battery banks. The monitors trend battery temperature, voltage, and internal resistance. These parameters indicate the overall health of the batteries
- **Online Generator Status and Health Monitoring** system that continuously monitor and trends generator operating status along with key electrical and mechanical parameters indicating overall generator health.

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Prevention of Cyber Intrusion

New software, especially related to wireless technologies, requires proper IT securities to prevent unauthorized access. For example, hackers who accessed debit and credit card information from Target in 2013 penetrated the Target network through the BAS. In implementing CBM upgrades, we ensure that all new software is evaluated by our cyber security professionals prior to selection. Consistent with NIST framework for securing information systems, our CBM data is mapped to information types described in NIST 800-60 and adheres to the moderate security and privacy controls described in NIST 800-53 for system usage. Additionally, the entire system environment is secured behind a firewall and connections to critical systems are further secured using internal firewalls. This approach to system protection is included in an Information Technology (IT) Security Plan, which is reviewed and updated periodically to prevent future potential threats.

Integrated Operations Center (IOC)

An additional portion of our CBM implementation was the expansion of the existing Energy Management Control Systems (EMCS) capabilities to collect, analyze, and act upon the CBM data. Our EMCS was transitioned into a 24/7/365 Integrated Operations Center (IOC) workspace. The IOC is the command post for monitoring the various BAS's, serves as the focal point of critical system monitoring/control and immediate HVAC response at any time, day or night. We added cubicles for four (4) technicians and engineers and modified existing EMCS Operator workstations to be more ergonomically efficient. We also added a video wall, and we upgraded the HVAC temperature control systems to accommodate the additional personnel and computer equipment.

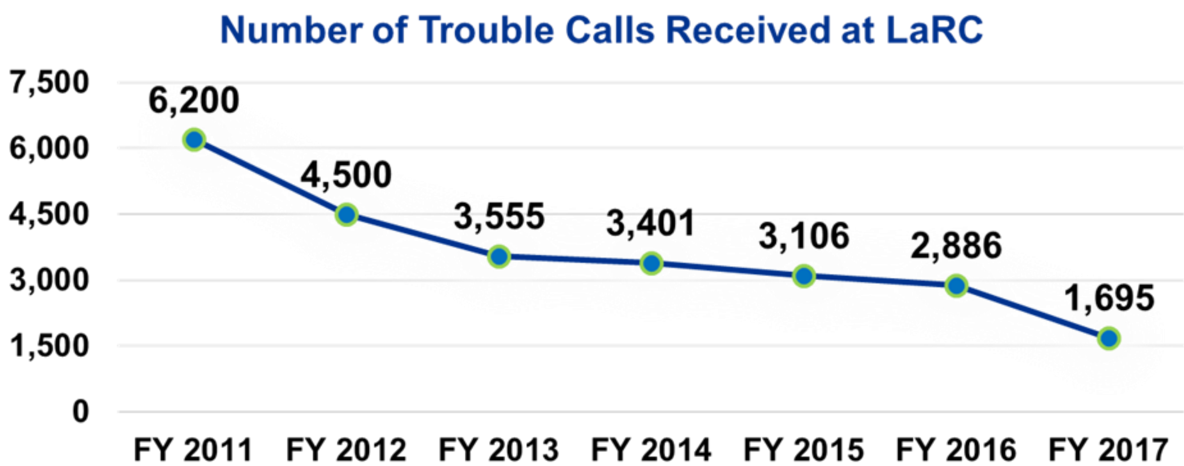
Economics of CBM

One of the most important aspects in justifying the implementation of CBM is budget. We often ask why we should invest in these technologies when other pressing issues need to be addressed. To help answer this question, we note that over a five-year period, Jacobs performed the following at NASA LaRC:

- applied Reliability Centered Maintenance (RCM) approaches,
- improved the data quality in the CMMS,
- focused on the quality and quantity of proactive work, and
- established sound metrics and KPIs to measure the state of the maintenance program

In executing the four noted points above, we reduced the overall cost of maintenance for our customer from $22M annually in 2011 to $13,7M annually in 2017 without a reduction in service levels. This 35% reduction in maintenance cost could not have been achieved—given annual salary increases, material cost increases, and the inherent cost of maintaining an aging infrastructure—without investments in areas such as CBM.

Though determining an accurate ROI for CBM is difficult without taking an educated guess of potential cost avoidances and downtime reductions for critical equipment failures, our historical trending data from our route-based predictive testing indicates a cost avoidance/cost savings of $1M- 1.3M per year or $5.3M to date. This number could increase by applying CBM to a greater quantity of critical systems. Additionally, users must critically assess spending on a per facility and per asset basis to determine the optimal opportunities for returns and to ensure that ROI calculations are accurate. Through the implementation of CBM at NASA LaRC, NASA has realized a significant increase in reliability and availability of their critical facility systems. The table below demonstrates the reduction on trouble calls received over a 7-year span that validates the effectiveness of the LaRC CBM program.



Conclusion

Jacobs has successfully managed CBM implementation at several large customer sites, including pre-program planning; design; development; subsystem and system level testing; and sustainment. We have reduced our clients' annual maintenance budgets, improved reliability, lowered operational risks, and reenergized our collective workforce by upgrading and refreshing their technical capabilities. Furthermore, to reduce implementation risks and maximize CBM effectiveness, we took the following steps:

- Benchmarked other CBM programs
- Utilized pilot programs to validate our approach to CBM and applied lessons learned from benchmark sites
- Employed an industry recognized third party consultant to assess our approach
- Documented best practices and lessons learned from the pilot program
- Developed a strategic plan and program implementation plan for our client complete with a Plan of Action with schedules and Milestones (POA&M)
- Identified projects for implementation by analyzing CMMS data and assessing ROI

- Integrate Operational Technologies (OT) and Information Technology (IT) requirements for data collection, analysis, storage, trending, and initiating subsequent actions

Recognition

Jacobs A&T Tidewater Operations Group that supports NASA at NASA's Langley Research Center in Hampton, Virginia was the recipient of the Reliabilityweb.org and the Uptime Organization's prestigious 2017 "Best Overall Reliability Program" of the year award. This award recognizes outstanding programs for their commitment to and execution of high quality Predictive Maintenance and Condition Monitoring Programs.