NATIONAL CENTER FOR MANUFACTURING SCIENCES

Condition-Based Maintenance Plus (CBM+) Protects High-Value Assets

Over the past several decades, industries with high-value assets have increasingly pivoted from reactive to predictive maintenance—also called Condition-Based Maintenance Plus (CBM+)—to reduce operational costs. Unlike reactive maintenance, which makes repairs to components after they break, and preventative maintenance, which schedules inspections, repairs, and replacements before parts become damaged, predictive maintenance/CBM+ is maintenance based on the evidence of need. The objective of CBM+ is to accurately detect the current state of mechanical and electrical systems and predict systems' remaining useful lives.

Through the application and integration of appropriate processes, technologies, and knowledge-based capabilities, CBM+ helps maintenance professionals achieve the target availability, reliability, operation, and support costs of systems and components across their lifecycle. As a maintenance philosophy, CBM+ uses a systems engineering approach focused on fault detection, diagnostics, degradation monitoring, and failure prediction.

How CBM+ Works

Sensors embedded in critical equipment components monitor the equipment's condition in near-real time, sometimes even while the asset is in use. For example, vibration sensors detect the amount of vibration in rotating equipment such as compressors, pumps, and motors, as increased vibration can indicate equipment degradation. Another type of sensor—a particle sensor—monitors hydraulic fluids and lubricants to track any changes in oil condition and to provide early warning of machine component wear. A third type of sensor, a thermal imager, scans equipment to detect temperature through infrared images, as heat can be an early indicator of machine damage.

These sensors report data to a computer system that interprets the data. The system detects deterioration in performance or impending failure. By calculating remaining life, the system provides the data for scheduling downtime for maintenance. When a sensor, inspection, or test identifies a condition that indicates failure is pending or equipment performance is deteriorating, maintenance is scheduled.

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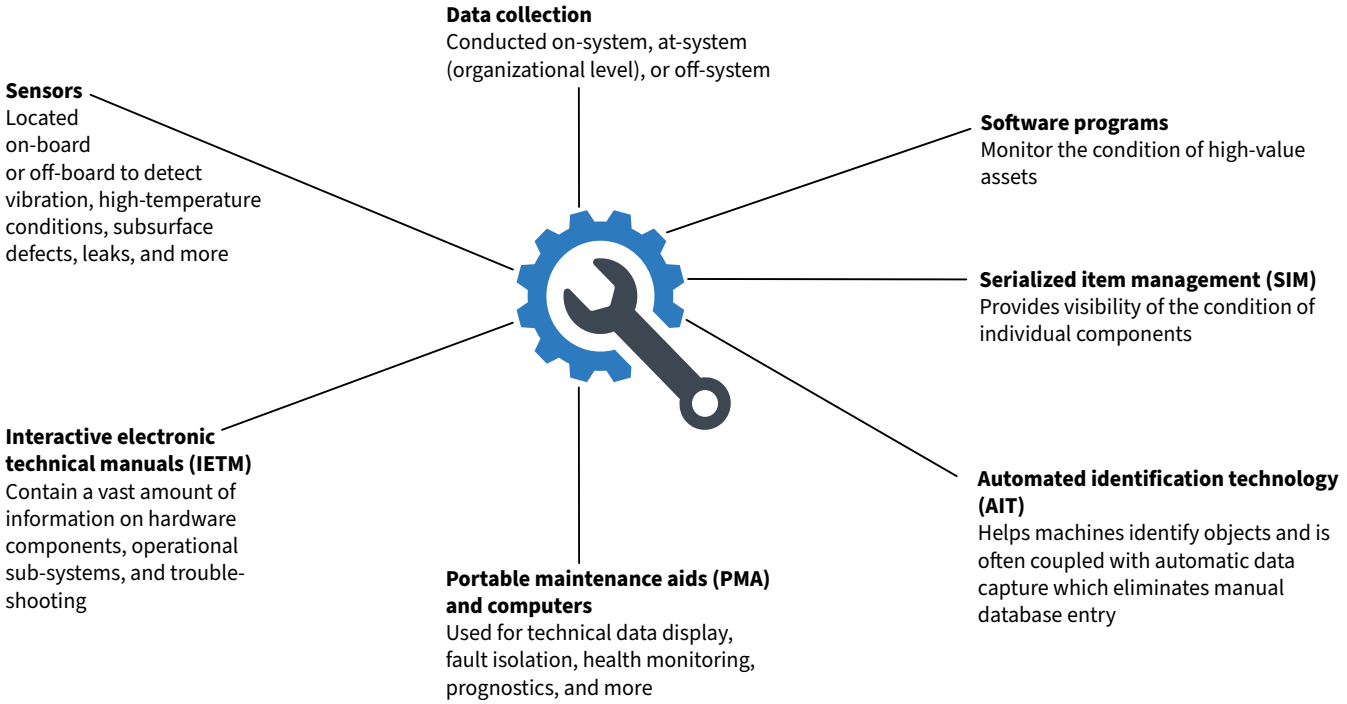
CBM+ involves several capabilities: analyzing equipment and system maintenance requirements, diagnosing equipment and system conditions, reporting condition status and maintenance data, performing mainte-

Technologies Required for CBM+



nance according to established guidelines for preventive maintenance (PM) and predictive maintenance (PdM), and total lifecycle management (TLCM).

CBM+ technologies provide the ability to diagnose system faults and upload operational data using test measurement diagnostic equipment (TMDE) and laptop or handheld computers. CBM+ relies on the ability to analyze all relevant data sets such as energy consumption, repair, and performance data, to discover equipment condition by using artificial intelligence, machine learning, algorithms, advanced analytics, digital simulation, digital twins, and physics of failure (POF).

Over the past twenty years, NCMS has brought together multiple industry and government partners to complete dozens of projects that have advanced CBM+ technologies. These projects have provided CBM+ support for a wide variety of equipment types including computer numerical control (CNC) machines, aircraft, maritime assets, tactical wheeled vehicles (TWVs), Caterpillar T5 Dozers, JCB High Mobility Engineer Excavators Type I (HMEE-I), and the M88 Heavy Equipment Recovery Combat Utility Lift and Evacuation System (HERCULES), among others.

NCMS has facilitated collaborations that have improved the application of CBM+ in four main areas: electronics, software, vehicle monitoring, and non-destructive inspection (NDI).

Electronics

Electronics are a crucial component of CBM+ and an active area of NCMS collaborations. One initiative focused on helping to detect degenerative conditions that could lead to

wiring failure—a crucial problem because wiring systems are the conduit that supports vital functions such as electrical power, control signal, and information distribution throughout a system. Wiring maintenance issues consume several million maintenance hours annually. This project inserted two types of electrical distributed analyzer (EDA) technology—the Eclypse ESP+ Standing Wave Reflectometer and the Eclypse RTS-501 Electrical Distribution Analyzer (EDA)—into multiple commercial and military aircraft maintenance depots. These tools help maintenance personnel rapidly identify and localize platform-wiring anomalies and malfunctions, and verify proper performance and integrity of all wiring system modifications.

For CBM+ to work, sensors must be able to operate in all conditions. An NCMS collaboration with industry and government partners focused on improving the sensors in Collision Avoidance Systems (CAS), which combine radar, laser, or camera-based systems to warn drivers of an impending collision. The problem is that many of these devices are mounted in harm's way with no protection from adverse weather conditions. This project ensured more durable sensor operations by integrating CAS sensors into robust, weatherproof assemblies that allow sensors to perform their required functions while enduring harsh environments and high collision crashes.

Software

NCMS has brought together multiple industry and government partners for collaborations that have advanced the software needed for effective CBM+. One initiative used artificial intelligence (AI) and machine learning (ML) to extract value from data and support effective decision-making regarding in-service maintenance and sustainment for ships used in the military and the commercial maritime industry. The collaboration took existing data for selected critical systems that are common across both military and commercial ships and demonstrated the value that best industry practice digital analytics can provide for ship operations, maintenance, and sustainment/life extension.

Another collaboration leveraged advanced commercial cybersecurity software, modular open system architecture, and security protection tools to ensure the security of a family of maintenance recovery vehicles and their on-board maintenance support devices and equipment. This project demonstrated how to reduce the possibility of a successful cyber-attack, and how to mitigate the potential consequences of a successful intrusion into other vehicles and maintenance support systems via wired and wireless entry points during maintenance activities.

Other NCMS-organized collaborations have utilized digital twin technologies, voice-directed technologies, and software such as Freedom eLOG® and GE's SmartSignal to efficiently, proactively address equipment performance degradation and optimize sustainment operations. Voice-directed technologies have become an integral data-collection source to predict future condition-based maintenance requirements. Freedom eLOG® is an asset monitoring system that collects and analyzes important manufacturing data in real time. GE's SmartSignal, used as part of a holistic predictive maintenance strategy, can detect, diagnose, predict, and prevent failures of critical assets.

Vehicle Monitoring

Several NCMS-facilitated collaborations have focused on using CBM+ for vehicles by improving data on fluid and fuel conditions, among other information. One initiative created a portable fluid testing and diagnostic tool that provides maintenance personnel with real-time assess-

ments of equipment fluid conditions. Another project evaluated the capability to upload telematics data from multiple vehicle fuel management systems into a centralized data system for CBM+ analysis. Telematics data includes data on vehicle use, maintenance requirements, and automotive servicing, all of which facilities proper fleet management.

A third collaboration focused on the collection, recording, and reporting of DOD non-tactical vehicle (NTV) fuel data to the defense priorities and allocations system (DPAS) to support the decision-making processes for vehicle acquisition, modernization, sustainment, and operations as well as fuel management compliance with federal regulation to reduce petroleum use and greenhouse gas emissions.

More recently, NCMS launched a collaboration to develop a state-of-the-art integrated vehicle health management (IVHM) system that will incorporate advanced diagnostics and prognostics capabilities into emerging and future US Army robotic and semi-autonomous ground vehicles.

Non-Destructive Inspection (NDI)

NDI is a valuable type of technology for CBM+. One NCMS collaboration leveraged significant advancements in development of high-frequency acoustic emission (AE) for monitoring the condition of rotating equipment. Acoustic emission (AE) is a passive inspection method that monitors the transient stress waves generated by the rapid release of energy from localized sources (e.g., fracture), within a material. Results indicated that the use of AE is viable and serves as a strong complement to vibration analysis.

Another collaboration used API's RapidScan 3D laser scanning technology to provide precision dimensional data of turbine rotor compressor blades and to provide higher precision surface/roughness measurement data. This technology accurately and consistenly inspected turbine rotor compressor balades, providing very fine details of quantitative analysis of erosion and cavitation.

Overall, CBM+ technologies improve maintenance performance in both private and public enterprises by facilitating:

- Greater productivity
- Shorter maintenance cycles
- Better equipment availability
- Lower costs
- Increased process quality
- Enhanced reliability

About NCMS

The National Center for Manufacturing Sciences (NCMS) is a cross-industry technology development consortium, dedicated to improving the competitiveness and strength of the U.S. industrial base. As a member-based organization, it leverages its network of industry, government, and academia partners to develop, demonstrate, and transition innovative technologies efficiently, with less risk and lower cost.

NCMS enables world-class member companies to work effectively with other members on new opportunities – bringing together highly capable companies with providers and end users who need their innovations and technology solutions. NCMS members benefit from an accelerated progression of idea creation through execution.