The significance of condition-based maintenance (CBM) and equipment health management (EHM) extends beyond equipment monitoring and repair into enterprise management and business intelligence.

Misconceptions usually surround difficult issues just as they do the subject of condition monitoring and maintenance practices. Based on observations in many industries, I have found three most prevalent and potentially damaging misconceptions. While these misconceptions need to be corrected to ensure healthy communication and productive technical exchange, they nevertheless provide a common ground for discussion of condition monitoring and maintenance technologies.

Misconception 1: Been there, done that

Many organizations and practicing professionals have used various degrees of condition monitoring and maintenance technologies in their routine operations, but they have come to the conclusion that these technologies are not suited for them for lack of consistent, measurable benefits.

Misconception 2: Same old stuff, no new trick

Similar to the group of organizations and professionals holding the first misconception, this group is reluctant to embrace newer technologies or methodologies, although they have not completely lost the hope for possible benefits.

Misconception 3: It is going to cost me

This misconception is frequently held among plant or resource management. Yes, it costs money to invest in (or implement) a good condition monitoring system, but the return on investment (ROI) may very well justify the cost. On the other hand, not implementing effective monitoring and maintenance practices may result in more costs for repair and support.

Evolution of technologies

Historically, a condition monitoring system (CMS) is a ground-based, or an on-board, system that performs some level of monitoring functions. These functions typically include exceedance alert, failure detection, and failure isolation.

The primary goal of a CMS is to help the maintenance crew repair damaged parts in reaction to alerts and failures. Hence, the practice is considered reactive maintenance (RM). As condition monitoring and maintenance technologies evolved, the goal of CMS was extended to failure prevention, i.e., implementing the preventive actions that are time-based (or schedule-based such as periodic inspections) to detect abnormal conditions and repair faulty parts. This type of maintenance practice is considered preventive maintenance (PM). More recently, CMS capability has been expanded to failure prediction, i.e., to predict when a failure will progress to the point where the service of equipment will be disrupted. This practice with an emphasis on failure prediction and associated maintenance actions is considered predictive maintenance (PdM).

To implement PdM effectively, a CMS must be able to identify root causes and optimize maintenance actions. Hence the PdM with an emphasis on the analysis of failure mode and effects as well as root causes is sometimes considered proactive maintenance. The maintenance practice driven by PdM or proactive is condition-based, hence it is also called condition-based maintenance (CBM).

While RM, PM, PdM, and CBM have been the terminologies commonly accepted in the industrial sector, a different set of terminologies has been adopted for the aerospace and defense sectors. An objective of this discussion is to bring condition monitoring and maintenance technologies in these different sectors together and to facilitate a sharing of best practices.

Since flight safety and airplane readiness are critical to mission successes in the aerospace and defense sectors, the development of monitoring and maintenance technologies has been accelerated. Aircraft condition monitoring systems (ACMS) and engine monitoring systems (EMS) have been implemented on flight vehicles for decades. Engine health management (EHM) systems, whose capability goes beyond the traditional recording and alarming functions of a CMS, have been implemented in helicopters for two decades (e.g., health and usage monitoring system, HUMS).

Since the mid-1980s, the reliability-centered maintenance (RCM) process has been applied to the aerospace and defense sectors. In the late 1990s, emphasis was further placed on the modeling and reasoning aspects of failure prediction as well as on the life extension of critical engine parts. Hence a total solution concept is evolving that tightly integrates monitoring, maintenance, logistics, and operations.

This total solution philosophy is called prognostics and health management (PHM) for the joint strike fighter under development by several countries armed forces. PHM aims to detect a wide range of operating conditions, including known failure modes, intermittent faults, and anomalies, while eliminating false alarms and missed detects. It also aims to prognosticate potentially damaging conditions based on the anticipated operating environment and available resources, i.e., spare parts. The U. S. Army considers this type of concept anticipatory maintenance. PHM or anticipatory maintenance expands PdM by providing a complete solution for engine or equipment health management (EHM).

Health management
An effective health management solution consists of four major steps:

- Measuring key system operational parameters
- Identifying abnormal conditions and predicting incipient failures
- Determining maintenance actions that make the best business sense
- Scheduling and controlling maintenance work.

These steps address the four fundamental questions of a comprehensive condition-based maintenance solution: where, when, what, and how, respectively.

Maintenance Intelligence
In the health management process, the two middle steps provide all the necessary functions from data analysis and prognostics to recommended maintenance actions. These steps form the Maintenance Intelligence (MI) that is essential to support the business objectives of equipment operators or owners.

Maintenance Intelligence consists of six major functions: data analysis, anomaly detection, health assessment, prognostics, life prediction, and maintenance decision support. Anomaly detection, health assessment, and prognostics are all related to abnormal conditions. Abnormal conditions occur at various stages of equipment service life. Depending on the stage in equipment service life and when the measurement is taken, abnormal conditions are classified and detected differently.

Anomaly, fault, and failure

Abnormal conditions can be classified into three groups: anomaly, fault, and failure. While many practicing engineers and maintenance associates consider them similar or synonymous, we prefer to look at them separately in the failure progression process. Anomaly is a type of abnormal condition.

We can define the functions of anomaly detection, health assessment, and prognostics as follows:

- Anomaly detection performs the function of detecting unknown abnormal conditions.
- Health assessment performs the function of detecting faults under known failure modes.
- Prognostics performs the function of predicting when the failure will occur after a fault condition is detected.

In some applications, predicting remaining life of equipment is included in the prognostic function. However, to be consistent with the scope of identifying abnormal conditions in anomaly detection and health assessment, we favor the idea of separating the life prediction function from the prognostic function, because predicting remaining equipment service life needs to consider factors other than failure state.

Decision support

Maintenance decision support acts as a bridge between condition monitoring and detailed maintenance task planning and scheduling. As described previously, condition monitoring identifies abnormal conditions and predicts when such conditions will deteriorate to disruptive failure states. Decision support takes the condition monitoring information and combines it with operations information to recommend the most adequate maintenance actions based on desired business objectives. After these maintenance actions are determined, detailed work tasks are planned and scheduled by a work control tool, typically an enterprise asset management or computerized maintenance management system.

Decision support is when condition monitoring information is transformed into maintenance actions so the benefits of increased equipment service life (or uptime) and decreased cost of ownership can be realized.

Business intelligence

The key to CBM is Maintenance Intelligence. It is essential for the kind of business intelligence that drives operational efficiency and enterprise excellence. Four types of systems are usually implemented in manufacturing or production facilities (or systems): control and operating system, monitoring system, maintenance system, and management system. The success of each individual system ensures the success of the enterprise.

Obtaining Maintenance Intelligence requires the application of many different analytical methods, ranging from traditional physics-based modeling to artificial intelligence (AI). An AI or a smart system usually contains a component of expert system, fuzzy logic, or neural network (NN). These smart components complement traditional analytical methods for information processing.

An artificial neural network is a mathematical tool modeled after biological brains. The primary advantage of NN over the traditional method is its learning ability, i.e., to learn patterns and features. This advantage makes NN a powerful tool in handling time-varying characteristics such as a fault signature or time-elapsed deterioration. It also offers significant benefit for implementing predictive models. See accompanying section "Advantages and Limitations of Neural Networks."

While NN processes numeric information, fuzzy logic and expert system process symbolic information. The fuzzy logic method is especially powerful in handling multi-valued computations; hence it is useful for reasoning or diagnostic functions.

A hybrid approach that combines both traditional and smart analytical methods and is capable of handling both numeric and symbolic information has proven to be most effective in obtaining Maintenance Intelligence.

A CBM or an equipment health management solution is the modern phrase for condition monitoring, health assessment, maintenance decision support, planning, and control. It supports RCM and PHM philosophies. It is manifested in PdM and proactive maintenance practices. Its significance extends beyond equipment monitoring and repair into enterprise management and business intelligence.

A critical link in the CBM process is Maintenance Intelligence. At the center of Maintenance Intelligence is decision support. Maintenance decision support is the bridge between monitoring and maintenance. It is also the driving force for realizing such business objectives as reduced equipment downtime, optimized spare inventory, leveled work scope, and reduced cost of ownership. **MT**

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