$399

ACM

ASSET CONDITION MONITORING PROJECT MANAGER'S GUIDE

RELIABILITYWEB.COM®

ACM ASSET CONDITION MONITORING
PROJECT MANAGER'S GUIDE

QUESTIONS REGARDING THIS DOCUMENT:

POSTAL: Reliabilityweb.com, 8991 Daniels Center Dr., Suite 105, Fort Myers, FL 33912 USA

PHONE: (888) 575-1245

WEB ADDRESS: http://www.reliabilityweb.com

E-MAIL: crm@reliabilityweb.com

EXECUTIVE SUMMARY

Many public and private sector organizations around the world have demonstrated that asset condition monitoring (ACM) is consistently capable of significantly increasing knowledge of asset condition and performance starting at the incipient stages of degradation. Owners, customers and stakeholders realize value by mitigating risks related to safety and the environment, as well as improving production, product, or service quality, all while reducing costs of operations and maintenance.

Despite the fact that successful approaches to ACM have been documented and refined over decades, not all organizations experience the level of success they desire. Dr. John Kotter, author of *Leading Change* reports that more than 70 percent of all major improvement efforts fail. Reliabilityweb.com research states that 70 percent of all reliability improvement efforts fail to generate sustainable business success. A *Plant Services* magazine 2016 random poll of over 200 organizations confirms that 65 percent of respondents rated their ACM programs ineffective or in need of improvement, while only 16.9 percent rated their programs effective or very effective. The rest (18 percent) considered their efforts “satisfactory.”

This ACM Project Manager’s Guide is created to address these less than very effective programs and to provide information enabling new programs to achieve excellence at the earliest possible time. It provides knowledge and success factors for anyone contemplating becoming a “champion” or project manager of a new, restructured, or expanding asset condition monitoring initiative within their organization to:

1. Provide knowledge of capabilities and tools needed to be successful;
2. Guide the decision to do or not do an ACM project of any scope (from initial start-up to expansion or restructuring) based on organizational readiness;
3. Measure initiative results to minimize risk of failure or abandonment and determine success during and after an ACM project.

The guide provides a clear, flexible process, with validating criteria so an organization can assess what it takes to successfully conduct and implement an ACM project and avoid pitfalls along the way. It shows how to measure results and add significantly to the bottom line.

Content includes lessons learned and the ingredients essential for success in a simple framework based on five essential ACM project phases:

Business Case Preparation → **Decision & Resource Allocation** → **ACM Plan Development & Procurement** → **Implementation & Short-Term Benefits** → **Integrated & Fully Effective**

This guide advocates a high-level team approach to steering efforts through the first four phases and into the fifth stage of a new start-up or major restructuring initiative. It also recommends that during the last two stages, one or more task teams made up of key working and first level supervisory members with different skills be formed and chartered with specific functions aimed at manning, equipping and planning how ACM will function as a fully integrated part of an overall asset management system. This guide also includes a primer on ACM fundamentals, a section dedicated to sustaining benefits while continuously improving, and a glossary of key terms. The references provide detailed information to aid in achieving success.

HOW TO USE THIS GUIDE

The Asset Condition Monitoring (ACM) Project Manager's Guide provides basic information about what an ACM initiative or organizational component is, how it should be conducted and who should be involved. The material is presented to help an organization determine if it is ready to undertake ACM and identify ideas and practices it must embrace or improve and pitfalls to avoid in order to enhance the chance of success.

THE GUIDE IS ARRANGED IN SECTIONS AS DESCRIBED BELOW:

Section	Title	What You Will Find
1.0	Introduction to Asset Condition Monitoring	Reasons and tips for using the guide
2.0	An ACM Primer	A foundation for applying the information in the guide
3.0	Starting, Expanding, or Restructuring an ACM Initiative	Basic, up-front requirements for success, from building a business case to getting approval to proceed, mitigating risk and avoiding pitfalls
4.0	Using Steering and Task Teams to Scope and Plan an ACM Initiative	Team makeup, mission and ACM plan outline of contents
5.0	Implementing the ACM Initiative and Reporting Progress	Steps to take, timelines involved and various options matched to your business process
6.0	Sustaining the ACM Component of a Maintenance Reliability Strategy	Values and capabilities required to continuously document results and identify areas to improve
7.0	References and Glossary	List of useful publications addressing ACM and definitions of important terms and concepts
8.0	Technology Insights	

1.0 INTRODUCTION TO ASSET CONDITION MONITORING

Asset condition monitoring (ACM) presumes that if left alone, the condition of all equipment will degrade sooner or later. This deterioration leads to partial or complete loss of function. Before the 2014 issuance of the ISO55000 asset management series of standards, ACM was formerly (and still is) called predictive maintenance (PdM).

The ACM approach monitors the condition and/or performance of critical structures, systems and components. ACM analysts detect emergent defects long before traditional maintenance practices would see or hear them. ACM technicians use the data to predict future outcomes, then technicians, maintenance and engineering teams act on the findings to limit deterioration and prevent complete failure. Some complex equipment may never fail completely if properly maintained. Parts and components of complex equipment may fail or be replaced to prevent their failure, preserving the asset as a whole from failing to accomplish its designed function(s).

There are as many definitions for the phrase asset condition monitoring or predictive maintenance as there are authorities and organizations involved with the subject.

The *Uptime® Elements™ Dictionary for Reliability Leaders and Asset Managers* defines asset condition monitoring or predictive maintenance as an advanced maintenance technique focused on using technology to determine the condition of assets and then taking appropriate actions to avoid failures. This is also known as condition-based maintenance (CBM).

One of the best explanations was developed by the Institute of Nuclear Power Operations (INPO), a nuclear-powered electricity generating industry watchdog organization established in Atlanta, Georgia, in the early 1980s. The explanation was in response to the Three Mile Island electricity generating plant reactor core meltdown accident in Pennsylvania in 1979. INPO defined predictive maintenance (with text put in bold by the author for emphasis) as:

> "*Those activities involving continuous or periodic **monitoring** and **diagnosis** in order **to forecast** component **degradations** so that as-needed, planned **maintenance** can be performed **prior to** equipment **failure**.*"

According to the Uptime Elements, asset condition management consists of three simple, yet potent concepts:

1. Stemming defects from entering the organization through the application of precision domain techniques, such as lubrication, precision alignment and precision balancing;
2. Using condition monitoring and nondestructive testing technologies to provide early detection of possible failure modes in order to optimize planning, scheduling and material requirements;
3. Creating a unified system for asset condition information management and decision support related to managing the condition or health of the assets.

The philosophy of asset condition monitoring is emphasized by the words of the definition in bold text and relating them to something humans are more familiar with: personal health.

- **Monitoring** means watching carefully.
- **Diagnosis** means to determine health status.
- **Forecast** means to project or predict future status.
- **Degradations** mean deficiencies relative to best possible health.
- **Maintenance** in the context of the definition means to return the health to normal.
- **Prior to failure** means before complete loss of function or incapacitation.

So, the philosophy of asset condition monitoring is to:

Watch carefully, determine health status on a continuous or periodic basis, predict future status based on deficiencies found, then maintain or return asset health to normal before complete loss of function.

ACM uses various sensors and presentations (e.g., pressure, temperature, vibration, ultrasonics, flow and electrical measurements, such as voltage, current, resistance and inductance) and fluid sample analysis results (e.g., oil or gas). With these sensors and analysis results of fluid samples, such as lubricants used in them, asset condition specialists obtain indications of system and equipment health, performance and integrity (e.g., strength) and provide information for scheduling timely corrective action.

To make good predictions, plant personnel must make a long-term commitment to systematic collection, analysis and presentation of the right data. Experience with the characteristic mechanisms of degradation of performance, condition, or integrity enables personnel to relate test and inspection results to failures. They must strive to gain sufficient knowledge to enable forecasting of deteriorating conditions and continuously work at improving their craft. The competency of your ACM team is a key element to building the reliability culture at your site.

ACM often provides maintenance personnel with the ability to assess the operating condition of equipment at any time and allows the monitoring of progressive deterioration of components without the necessity for physical person inspection. Condition monitoring provides useful information to diagnose and correct problems early in the aging or failure sequence. This permits maintenance to be planned and scheduled with minimal impact on plant operation. ACM is generally non-intrusive and does not interfere with equipment control functions or instrumentation. In fact, it may use some of these indicators as predictors of the onset of degraded performance.

The application of ACM techniques and technologies has been found to significantly enable advanced maintenance reliability strategies to be adopted by thousands of facilities in industrial, commercial, government military and non-military, utility and almost all other conceivable venues worldwide. However, this doesn’t happen without leadership and the establishment of a reliability culture.

1.1 Creating a Reliability Culture

Regardless of how good your asset management system and reliability strategy is, your organization’s culture will determine its performance. Culture is built from within. A reliability culture must be cultivated and managed by leaders who aim to engage employees in delivering performance excellence in an organization. The reliability culture objective is the most important element of a successful program. All other objectives rely on the success of your team to acquire this reliability way of life.

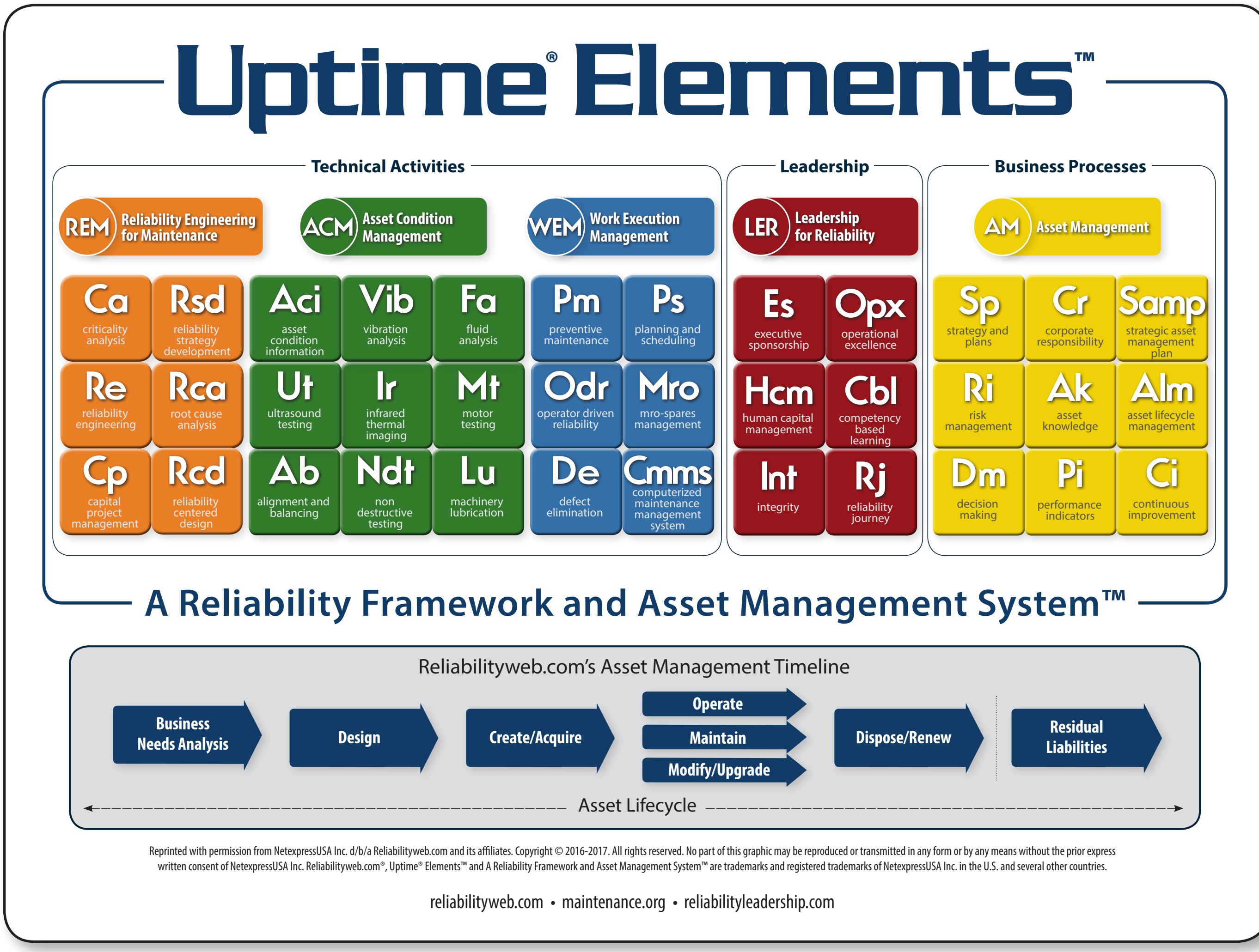


Figure 1: Uptime® Elements™ – A Reliability Framework and Asset Management System™

The Uptime Elements chart, shown in Figure 1, provides a map of theory by which to understand reliability leadership and begin creating a culture of reliability. The proven approach to successful asset condition management (ACM) and work execution management (WEM), using the **green** and **blue** colored elements, respectively, must be supported by the reliability engineering for maintenance (REM) **orange** elements on the left side of the chart. These comprise the technical activities which must be supported by the leadership for reliability (LER) **red** and business process asset management (AM) **yellow** elements on the right side in Figure 1. The combination of technical excellence and empowered leadership at all levels is by far the most significant indicator of a successful reliability strategy and program, and an organization that delivers significant results to all stakeholders.

1.2 The Body of Knowledge

The Uptime Elements works seamlessly with international standards. According to the recently published ISO55000 asset management standard, an asset is something tangible or intangible that has potential or actual value to an organization. Asset management is a coordinated set of activities to realize that value. The Uptime Elements enables asset management by assuring capacity and function of the assets where value is demanded.

The recipe for success found in this guide is derived from industry, government and other venue best practices learned and communicated from dozens of practitioners involved in creating the body of knowledge behind them. For example, Reliabilityweb.com has hosted forums, special interest groups and highly experienced volunteer practitioners who have contributed content for a series of *Uptime Elements Passports* addressing each of the 36 elements. These are shown in Figure 2. In addition, authors well known to practitioners in the field of reliability and asset management have written books that help readers navigate the most successful paths to achieving excellence in skills needed to master reliability, some of which are depicted in the 36 element passports in Figure 2.

Figure 2: Uptime® Elements™ Certified Reliability Leader™ Complete Body of Knowledge

Those who aspire to leadership in this field may pursue recognition of their acquired skills by becoming certified as a reliability leader. These documents, which constitute the body of knowledge upon which the certification is based, are illustrated in part in Figure 2. Also see Reference 5 in Section 7.1 of this guide.

1.3 The State of Asset Condition Monitoring (Predictive Maintenance) Today and What to Do About It

Despite the fact that successful approaches to ACM have been documented and refined over decades, not all organizations experience the level of success they desire. A *Plant Services* magazine 2016 poll of over 200 organizations reveals that:

65% of respondents rated their ACM programs **ineffective or in need of improvement**

16.9% rated their programs effective or very effective

18% considered their efforts "satisfactory"

From 2014 to 2016, the share of respondents who reported **dissatisfaction** with their program **grew by 9.2 percent,** with most respondents changing their answer from "satisfactory" to "needs some improvement." It's worth noting that the **total share of respondents who rated their programs "effective" or "very effective"** ***dropped*** by nearly 15 percent.[1] This indicates there is much work to be done to achieve excellence in this field. This guide has been developed to stimulate movement toward this goal for the vast majority of organizations that can benefit from properly formulated and managed ACM.

The contents of this guide are based largely on the book, *Asset Condition Monitoring Management* by Jack R. Nicholas, Jr., P.Eng., CMRP, CRL, IAMC, and published by Reliabilityweb.com (see Reference 1 in Section 7.1 of this guide). It is aligned with published standards, Reliabilityweb.com's CRL Body of Knowledge and Uptime Elements. It is hoped your organization has great success with ACM and your journey offers you a similar opportunity to contribute back to the community what you learn.

[1] Wilk, Thomas. "2016 PdM survey results - Part 2: Program investment and satisfaction." *Plant Services* magazine: March 2016. Change compared to 2014 survey results conducted jointly by *Plant Services* Magazine and ARC Research.

2.0 AN ACM PRIMER

New ACM start-up or major restructuring initiatives require strong rationale and careful management of change to assure success. This effort to achieve a reliability culture using a phased approach with the right personnel operating as teams with specific goals has been found to ensure success. Figure 3 illustrates the phases and timelines for steering and task teams who should be involved in these phases.

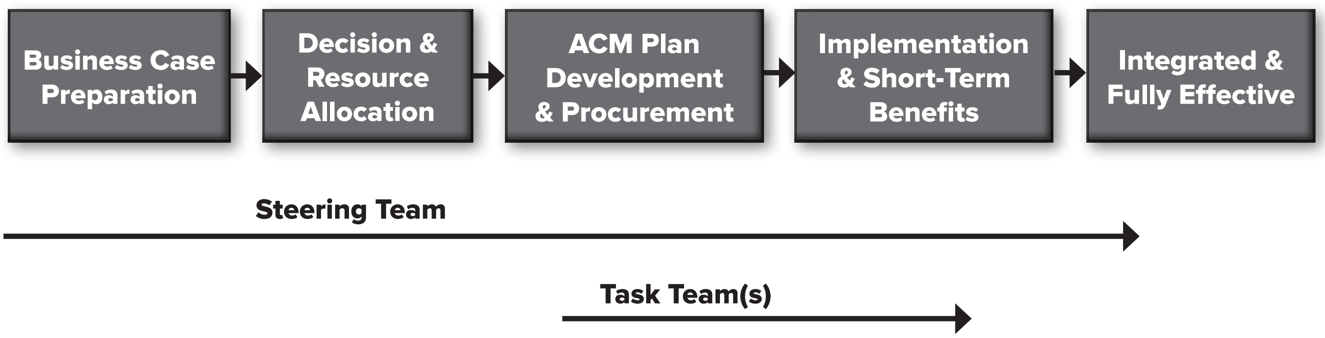


Figure 3: Phases for an ACM program

A typical timeline for an ACM new program start-up or major restructuring (e.g., bringing a contractor-supplied effort in-house) is illustrated in Figure 4.

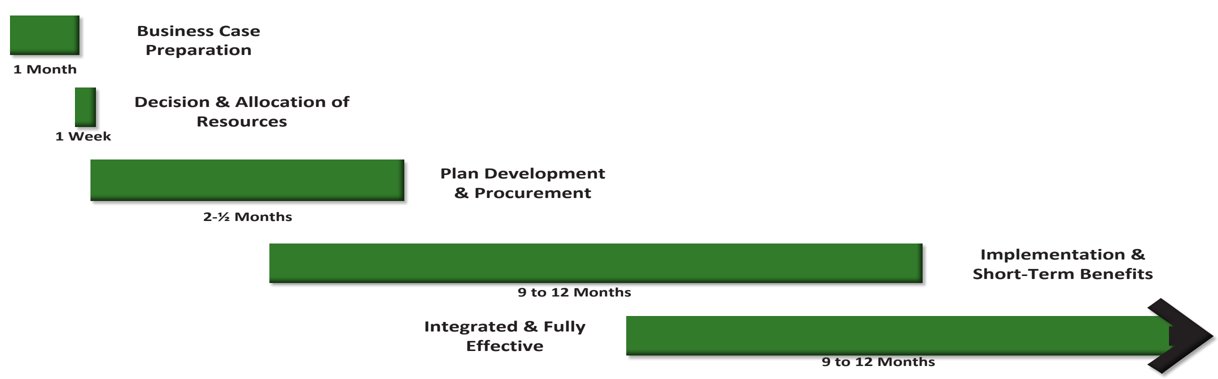


Figure 4: Example of a timeline of an ACM program start-up or major restructuring

The timeline for a new program or major restructuring may be as long as two years before full integration, acceptance by all interested parties and stability. Once a formally planned program is established, the timeline for expansion depends on several factors, such as more assets being added for coverage by technologies already available, additional ACM technology being applied and the number of ACM personnel available or needed and their workload. In any case, the timeline for expansion is shorter than a new or significantly restructured program. This is illustrated in Figure 5.

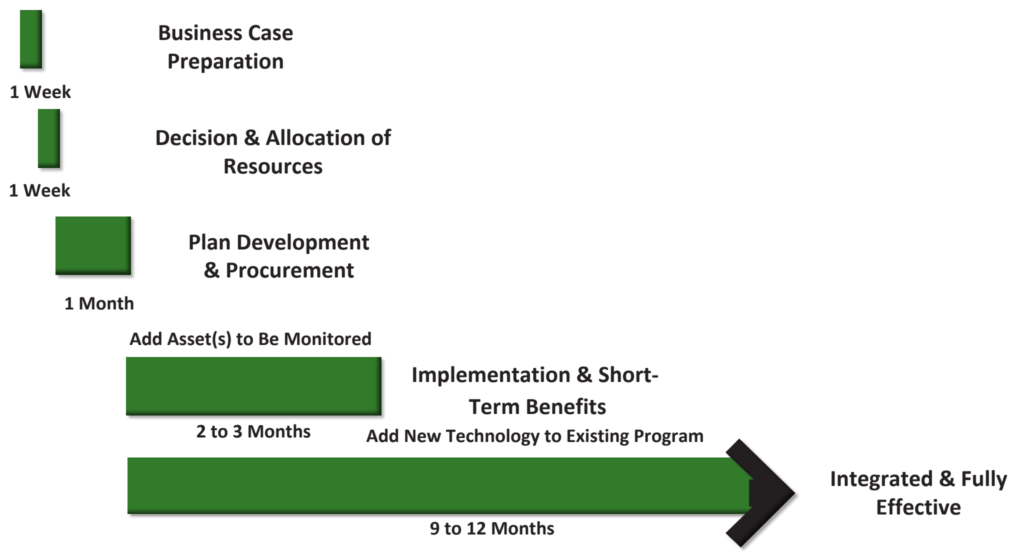


Figure 5: Example of a timeline for phases of an existing ACM program expansion

2.1 Executive Sponsorship in Business Case Preparation Phase

Starting a new or restructuring an existing ACM program typically requires an executive level decision by someone who can commit required resources or require those who control them to do so. The best way to make this happen is to build a convincing business case. Such a case should be steered by key stakeholders who have knowledge or access to data to help make the case or prove the proposed initiative has no merit.

A business case captures the reasoning for initiating a project or task. The logic of the business case is: whenever resources, such as money or effort, are consumed, they should be in support of a specific business need. For example, there may be a need for better performance to improve customer satisfaction, require less task processing time, or reduce system maintenance costs. A compelling business case adequately captures both the quantifiable and non-quantifiable characteristics of a proposed project.[2] Other benefits may be to reduce risks of regulatory noncompliance and fines, or improve reliability of assets to designed capability.

Business cases can range from comprehensive and highly structured, as required by formal project management methodologies, to informal and a brief report. Information included in a formal business case might be:

- Background of the project;
- Expected business benefits;
- Options considered, with reasons for rejecting or carrying forward each option;
- Expected costs of the various project options;
- Gap analysis relative to established best ACM practices;
- Expected risks.

The executive sponsor that requests and must rule on the business case sets the scope of the report required for decision-making. Some or all of the above information may be addressed in the presentation taken to the decision maker. Consideration also should be given to the option of doing nothing, including the costs and risks of inactivity. From this information, the justification for the project is derived.[3]

The executive sponsor/decision maker may conclude that outside assistance by a Certified Reliability Leader who is knowledgeable in ACM management is needed to support the initiative and allocate resources to acquire help to work through the internal ACM champion and assist in one or more phases of the project. The designated internal ACM champion incorporates steering team inputs, performs or oversees the research needed to back up the decision and prepares or guides the business case report and/or presentation preparation, assuring any dissenting views (e.g., from steering team members) are included. In some situations, where entrenched opposition to change or other objections have stifled progress in the past, a one or two day workshop with all interested parties present may be conducted to discuss grievances and provide an opportunity for resolution or rejection. Having an experienced facilitator – ideally one knowledgeable in ACM

---

[2] Messner, W. *Making the Compelling Business Case*. Houndmills: Palgrave Macmillan, 2013, and Wikipedia free encyclopedia entry “Business Case.”

[3] Ibid.

technologies and management, but not absolutely necessary – can provide opportunity for those attending to discuss their grievances and opinions with decision makers and at least have that satisfaction, even if their objections are rejected and the initiative goes ahead anyway.

Various publications in the field of maintenance reliability, including *Uptime*® magazine, *Vibration Institute* magazine, *Plant Engineer* magazine and others, contain multiple articles describing the benefits of ACM. The archives of each are available on the Internet. In addition, ACM technology vendor websites contain many case studies showing benefits. At the annual International Maintenance Conference (IMC), *Uptime* magazine's "Best ACM Program of the Year" awards (among many others) are presented, along with presentations by award winners on their achievements. Other sources include proceedings of annual conferences held by Vibration Institute (VI), Reliable Plant, the Institute of Asset Management (IAM), and the Society of Tribologists and Lubrication Engineers (STLE) that contain papers describing success stories about ACM. The Solutions 2.0 Virtual Conference provides short, 18 to 20 minute online presentations, some of which document return on investment data and other ACM key performance indicators. Websites, such as the Association of Asset Management Professionals (AMP), have maintenance forums that contain hundreds of items from a wide variety of venues, many of which document the benefits of applying ACM in an overall reliability strategy.

2.2 Decision and Resource Allocation Phase

With the mass of existing information, along with new information that continues to be added from previously mentioned sources, it is presumed a presentation and compelling business case would lead to an executive decision that will move an ACM initiative forward. A decision *not* to proceed or establish some form of an ACM program seems unlikely in all but the smallest organizations.

If the decision is to proceed, the responsible executive must then decide on the scope of the effort by selecting one or a combination of options presented in the business case and allocate both human and financial resources needed to move the ACM plan to the development stage.

Conventional wisdom for new start-up initiatives is to start small (e.g., with a pilot program) and build on success after learning lessons. For organizations with a more urgent need to get on with an advanced reliability and asset management strategy, proportionally more human and financial resources should be allocated early on. The steering team should anticipate more demands for its time to review progress and act to remove obstacles to success of the initiative. Task teams (described in Section 4.0 of this guide) should be formed promptly and charged with tight deadlines to start and complete their activities.

2.3 ACM Plan Development and Procurement Phase

The initial version of an ACM program plan should provide:

- An ACM program overview and the reliability culture philosophy to be followed, goals and scope;
- Technologies to be employed initially and in the future;
- Positions to be filled and source(s) for personnel;
- Responsibilities to be carried out;
- Organization;
- Communications paths and vehicles to be employed;
- Process diagrams and titles, or categories of procedures to be used;
- Safety and risk factors involved and their mitigation;
- Key performance indicators (KPIs) to be used to assess performance of the program;
- A framework for future entries concerning what assets (e.g., ACM tools) were actually procured and their cost;
- Training and certifications held by new incumbents upon reporting and to be acquired thereafter;
- Five-year budget;
- Schedule(s) for key milestones to be met annually and in out-years.

The outline of a typical ACM program plan is illustrated in Figure 6 (See Page 17).

It is important to realize that the ACM plan must be a living document. After initial formulation and during the implementation phase of an ACM initiative, the document may have to be changed several times to incorporate lessons learned, add new information of historical value and refine processes needed to fully integrate into the overall strategy.

<table>
<tr><th>Front Pieces</th><th>Title Page</th><th>Table of Contents</th><th>Change Page</th><th>Summary or Executive Summary</th><th>Foreword</th><th colspan="2">Introduction</th></tr>
<tr><td rowspan="2">Body of the Plan</td><td>Program Overview Goals, Scope</td><td>Team, Supporting Organization(s) & Plans</td><td>Best Practices</td><td>Roles & Responsibilities</td><td>Tools</td><td colspan="2">Processes</td></tr>
<tr><td>Procedures</td><td>Key Performance Indicators (KPIs)</td><td>Safety & Risk</td><td>Training & Certification</td><td>Management & Communications</td><td>Budget</td><td>Schedule</td></tr>
<tr><td>Annexes</td><td></td><td>KPI Details</td><td></td><td>ACM Team Member & Maintenance Crew Training & Certification Plans</td><td>Vibration, Infrared, Lube & Wear Particle, Ultrasonic & Motor Analyses + Alignment</td><td colspan="2"></td></tr>
</table>

Figure 6: Outline of a typical ACM program plan[4]

Once an ACM plan and the program it describes have stabilized and are integrated into the overall reliability strategy, opportunity for further growth may be undertaken as needed. Annual updates of the plan should become routine. After some time, the reliability culture is established and these activities become part of everyday life.

2.4 ACM Implementation and Initial Benefits Phase

New or significantly restructured and especially expanding ACM programs almost always follow a common path of development. At the beginning of data collection and analysis, there is a large increase in the number of defects reported as each technology or asset group is added to those being monitored. Many of these defects will result in work orders being initiated for corrective action. Many defects have existed and "lived with" for a long time. Operators and maintenance personnel become adept at applying work-arounds to compensate for the defects, even when they don't know what caused them. The ACM initiated work orders will correct many problems previously tolerated, but some metrics may move in adverse directions at the beginning of an ACM initiative implementation. This may not be well received unless analyzed and explained very carefully. For example, it is common to see an initial, temporary growth in the number of

[4] Nicholas Jr., Jack R. *Asset Condition Monitoring Managemen*t. Fort Myers: Reliabilityweb.com, 2016. Chapter 7 contains detailed descriptions of each item in Figure 6.

work orders (i.e., the hump or bow wave effect from expanding the maintenance backlog) and an increase in expenditures for replacement parts and more maintenance labor hours. This hump in work orders, parts requisitions and associated expenditures, as well as labor hours, must be overcome before positive results, reflected in other benefits, such as improved reliability, availability, product quality and throughput, are realized. It may take 12 to 18 months to work through this. For that reason, any of the metrics used during the benefits phase should be tracked long after the end of the implementation phase of an ACM initiative. Ultimately, the metrics will move in the desired directions. See Section 5.3 of this guide for a list of metrics affected by ACM initiatives and the desired directions toward which they should ultimately move.

The accumulation of early finds that creates the hump effect is illustrated in Figure 7. It shows an actual plot of condition monitoring finds after a major restructuring from contractor provided to a largely in-house ACM program.

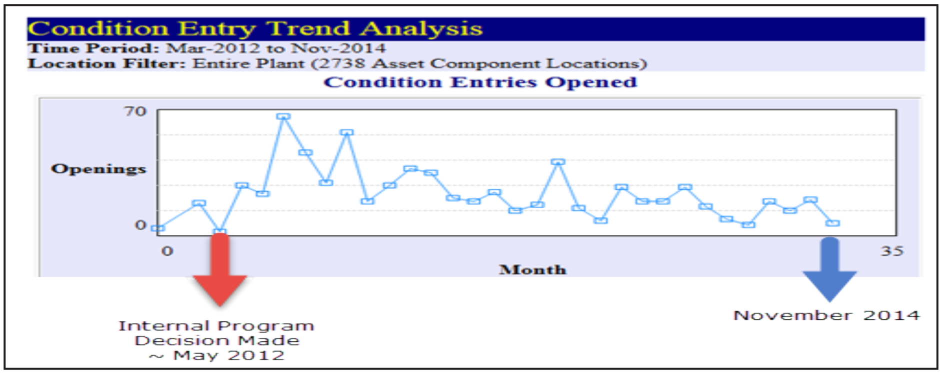


Figure 7: Condition entry trend analysis

Some chronic problems may not yield to an ACM solution alone. Often, these types of problems require a different approach, or advanced problem-solving. It may be useful to report metrics, such as failure rates, on these items separately or with caveats explaining the situation.

Those having to act on the ACM initiated work requests are often incredulous because, to them, the assets may appear to be functioning very well. Their opinions of the value of an ACM program may not be very good during the early months of implementation when the backlog of work orders is growing and the need for labor hours to reduce it grows. However, the reported defects, when corrected, represent opportunities for bringing the assets closer to the designed in level of reliability. Fewer high cost, unexpected failures will result in more uptime and quality, and in the long run, less corrective or reactive maintenance work hours and fewer forced outages.

If the ACM plan has mandated KPIs that report monetary benefits showing the difference between allowing an asset to run to complete failure and making repairs based on ACM finds, then the benefits become apparent to almost all concerned. Repairs resulting from ACM finds almost always are less costly, less labor intensive and more routinely done during regular work days instead of nights, weekends and during holidays. In addition, they are safer to perform in most cases, a fact that ultimately becomes obvious to early skeptics and detractors who want to criticize the messenger (i.e., the ACM technician) for adding to their workload. Monetary benefits (i.e., cost avoidance and cost saving actions) rapidly accumulate while an organization is working through the hump period. In fact, there are usually enough so only a portion of these benefits may need to be calculated to make program justification apparent. It is most important for the ACM team to keep track of these cost avoidance and cost saving KPIs. When the newness wears off and the equipment seems to be running better, sometimes people forget why they are doing ACM. The data will be there to remind everyone that you are on a continuous improvement path.

2.5 ACM Integrated and Fully Effective Phase

Once through the implementation phase of a new start-up, the number of ACM related work requests normally reduces to a steady level, well below the peak reached at the hump and even lower than before the ACM initiative started. That level is determined by the number of assets monitored, the sophistication and achievements produced by the rest of the maintenance reliability strategy, the number of ACM technologies employed, along with other factors. It is then that the ACM team can look to broaden its scope to other critical assets.

Knowledge level is raised by training and experience

The level of sophistication of the ACM program as an overall strategy is determined by the knowledge level of the participants. Knowledge level is raised by training and experience, and employing the technology or technologies assigned. Proof of proficiency is often established by mastery of certification scheme(s) for one or more technologies.

In Figures 4 and 5, there is an overlap in time between Phases 4 and 5 of a typical start-up, major restructuring, or adding a new technology to an ACM program. These phases are where training, experience and certification processes take place. The arrows on the final phase timelines indicate this is a never-ending process. When experienced, certified, or fully proficient ACM personnel move on, their replacements, who haven't achieved the same level of proficiency, are brought into the program. As such, some or all of the final phase processes of training and gaining experience, as well as certifications, must be repeated to keep the program at full functionality and effectiveness.

Schemes for certification vary by technology. Different organizations have embraced specific ACM technologies and developed requirements for becoming certified at one or more levels. The Ohio-based American Society for Nondestructive Testing (ASNT) has established requirements for prerequisites, training, on-the-job experience (hours) and a certification exam based on body of knowledge listings for ACM technologies, such as vibration analysis (to three levels), infrared thermography (to three levels) and visual testing/inspection (to three levels).[5] The Oklahoma-based International Council for Machinery Lubrication (ICML) has done the same for machinery lubrication technicians (to two levels) and related skills, such as on-site and laboratory lubrication analysts (to three and two levels, respectively).[6] Commercial organizations, such as ACM hardware and software vendors and ACM services companies, have done the same, but to a lesser extent for passive ultrasonic analysis (to two levels), on-line and off-line motor electrical testing (one level for each). The Illinois-based Vibration Institute has established certification requirements for vibration analysts to four levels or categories, each with its own formal training, on-the-job experience and certification exam requirements.[7]

Harmonization of requirements for certification in some ACM technologies has occurred between European (International Organization for Standardization - ISO and International Electrotechnical Commission - IEC) and U.S. based organizations. The gold standard in certification examination schemes is achieved when accreditation in accordance with ISO17024 personnel certification standard is granted by an authorized auditing organization, in the case of the U.S., by the American National Standards Institute (ANSI).

---

[5] See SNT-TC-1A Personal Qualification and Certification in Nondestructive Testing available for purchase from the ASNT website: www.asnt.org

[6] See the International Council for Machinery Lubrication website for an outline of courses and certification requirements: www.lubecouncil.org

[7] See the Vibration Institute website: www.vi-institute.org/certification

Most commercial and industrial organizations do not have sufficient in-house resources to train and examine candidates to various levels of certification. They depend on ACM training and certification organizations (ACMTCOs) to provide these services and document successful completion of requirements. There are no known requirements for formal certification established by regulatory agencies as of 2016 for predictive condition monitoring technologies, such as vibration or ultrasonic analysis, or infrared thermography, motor testing, lubricant and wear particle analysis, visual testing/inspection, or any other ACM technology. Comprehensive consensus **standards** for training and assessment of personnel in condition monitoring technologies are found in the ISO18436 series of documents. Because there are no known regulatory requirements for formal certification, many large companies, like General Motors, have set up standards for certification and levels of acceptance from vendors. They have established standards for training personnel and the amount of time needed at each level before they can qualify to move on to the next. Also, when accepting rebuilt equipment, like motors and pumps, they require the vendor to reach a high-level of alignment and low vibration signatures before returning the equipment to them. There are some regulations for nondestructive testing training and certification for skills in radiography, magnetic particle testing, active ultrasonic examination, leak testing and some other technologies, especially in the nuclear industries and for assets, such as pressure vessels, boilers and high pressure pipelines.

The amount of training and established levels of certification for ACM technicians are more a function of perceived need for various purposes by an organization's management. For example, training and certification are supported as incentives for technicians to add to their skills, serve the organization more effectively and, where offered, be better compensated. By establishing personal goals for successful ACM training and certification achievements, organizations can provide a career path and a "what's in it for me" element for their technicians that helps to retain them for as long as possible in those positions.

In general, the time required for an ACM technician to achieve full competency depends on the timing of the training, the number of assets monitored, opportunities to practice the use of the technology and many other factors. Based on experience with many different ACM initiatives, an informal survey of ACM hardware and software vendors and some ACM technicians at the 2016 SMRP annual conference, the months required to achieve competency in a given ACM technology at Levels I and II are provided in the second column of Table 1. It is not uncommon for ACM team members to become certified, or at least competent, in two or three technologies, in addition to being certified in visual testing/inspection. An ACM program where technicians cross-trained in two or more predictive sciences will usually have faster and more complete problem-solving. The length of time to become competent and/or certified typically overlap. After achieving Level I and starting on Level II, candidates may also start to achieve competency in a second technology. The length of time for ACM technicians to achieve real proficiency or competency depends on the scientific complexity of the principles of the technology, frequency of monitoring, when and where in the process the training takes place, availability of on-the-job mentors, such as ACM contractors already monitoring on-site assets, and prior education and aptitude of the technician for mastering related bodies of knowledge as demonstrated by passing practical and written examinations.

As a practical matter, the level to which ACM technicians should be certified depends on what is offered in the marketplace and the needs of the organization in which they are employed. Examples of ACM certification goals for the commonly applied technologies are shown in Table 1, along with references to applicable parts of ISO18436.

Table 1 – Example of Certification Goals for ACM Team Technicians

Technology	Certification Level & Months to Full Competency	Requirements of ACM Training and Certification Organizations (ACMTCOs)	Comments
Vibration Analysis	Level I 9 to 12 months	Attend ACMTCO vibration analysis Level I training courses and pass written, oral and/or practical exams based on content. Document required hours of field experience before or after each course before mastering a relevant certification exam.	Some ACMTCOs require completion of a 20+ item checklist of vibration analysis related learning task items prior to admission to the basic Level I training course. SNT-TC-1A specifies training and field experience hours needed for Levels I and II.
Vibration Analysis	Level II additional 9 months to 1 year	Attend ACMTCO vibration analysis Level II training course. Document required hours of field experience and pass written, oral and/or practical exams based on content.	ASNT Standard Topical Outlines for Qualification of Nondestructive Testing Personnel (ANSI/ASNT CP-105-2016) outlines course requirements for Levels I and II. An alternative is to follow the Vibration Institute's Categories 1 through 4 requirements which are based on ISO18436 Part 2 Vibration condition monitoring and diagnostics.
Infrared Thermography	Level I 6 to 9 months	Attend ACMTCO Level I infrared thermography course and pass written, oral and/or practical exams based on content. Document required hours of field experience after course completion.[1]	SNT-TC-1A specifies training and field experience hours needed for Levels I and II certification. ISO18436 Part 7 (ISO18436-7) provides qualification and assessment requirements for thermography.
Infrared Thermography	Level II additional 9 months to 1 year	Attend ACMTCO Level II infrared thermography course and pass written, oral and/or practical exams based on content.	ASNT Standard Topical Outlines for Qualification of Nondestructive Testing Personnel (ANSI/ASNT CP-105-2016) outlines course requirements for Levels I and II.

Table 1 – Example of Certification Goals for ACM Team Technicians (Continued)

Technology	Certification Level & Months to Full Competency	Requirements of ACM Training and Certification Organizations (ACMTCOs)	Comments
Ultrasonic Analysis	Level I 4 to 6 months	Attend ACMTCO Level I training course and pass written or oral and practical exams. Document required hours of field experience after course completion.	Vendors of hardware and software suites and ACMTCOs offer courses, recommendations for field experience and hands-on practical exams and/or mentoring.
Ultrasonic Analysis	Level II additional 4 to 6 months	Attend ACMTCO Level II training course and pass written exam.	Training courses based on ISO18436-8 (Ultrasound) meet the ISO Technical Committee 108 (ISO/TC 108) Subcommittee 5 consensus.
Motor Circuit Off-Line Testing	Level I 4 to 6 months	Attend ACMTCO de-energized motor circuit testing course and pass written exams on theory and equipment, and one-on-one practical exam on equipment.	There are no recommended equivalent training and field experience requirements from professional organizations/societies. Vendors of hardware and software suites offer courses, recommendations for field experience and hands-on practical exams.
Motor Circuit On-Line Testing	Level I 4 to 6 months	Attend ACMTCO energized motor circuit testing course and pass written exams on theory and equipment, and one-on-one practical exam on equipment.	There are no recommended equivalent training and field experience requirements from professional organizations/societies. Vendors of hardware and software suites and ACMTCOs offer courses, recommendations for field experience and hands-on practical exams.
Visual Testing/ Inspection	Level I	Complete ACMTCO visual inspection Level I training course and written and practical examinations.	SNT-TC-1A specifies training and field experience hours needed for Levels I and II.
Visual Testing/ Inspection	Level II additional 2 to 3 months	Complete Level II training course and written and practical examinations.	ASNT Standard Topical Outlines for Qualification of Nondestructive Testing Personnel (ANSI/ASNT CP-105-2016) outlines course requirements for Levels I and II. Courses are typically taken back-to-back and competency achieved at Level II thereafter on the job.
Machinery Lubrication Technician and/ or Analyst	Level I 9 to 12 months	Complete ACMTCO Level I machinery lubrication technician or machinery lubrication analyst training course and exam(s) of the International Council for Machinery Lubrication.	Requires two years of education (post-secondary) or on-the-job training in one or more of the fields of machine lubrication, engineering, mechanical maintenance and/or maintenance trades.
Machinery Lubrication Technician and/ or Analyst	Level II additional 6 to 9 months	Complete ACMTCO Level II machinery lubrication technician or machinery lubrication analyst training course and exam(s) of the International Council for Machinery Lubrication.	Requires three years of education (post-secondary) or on-the-job training in one or more of the fields of machine lubrication, engineering, mechanical maintenance and/or maintenance trades, which are based on Parts 4 and 5 of ISO18436.

[1] Documentation of field experience requires a handwritten or digital log of dates, hours, plant and number of finds. This also applies to on-the-job experience documentation for other technologies.

3.0 STARTING, EXPANDING, OR RESTRUCTURING AN ACM INITIATIVE

Organizations risk failure of ACM initiatives if they are not ready. Establishing a reliability culture is the most difficult thing the ACM team will accomplish. It is impossible to reach the desired outcomes and get sufficient support and buy-in from all levels if they don't understand what roles and responsibilities must be assigned and don't know how to properly establish a framework to assure sustainability and maximum capability. This chapter describes how to avoid the pitfalls and apply best practices in establishing a successful program.

3.1 Readiness of the Organization

Basic requirements for assuring success of an ACM initiative include the organization readiness factors listed in Table 2.

Table 2 – ACM Readiness Factors

Readiness Factors	Yes or No	What to Do Next
Do I have a Certified Reliability Leader (CRL) implementation champion to oversee conducting and implementing an ACM program start-up, upgrade, or restructuring?	Yes	Engage. Designate him/her to champion the ACM initiative. Consider hiring an experienced outside facilitator to assist the champion. Align expectations for deliverables, methods and outcomes during the time a facilitator is required.
	No	Without one, the chances of success are dramatically reduced. This guide recommends a no-go decision. First, educate staff and stakeholders on the benefits of ACM.
Is current leadership and staff aligned with the desired outcomes of the proposed program and support a steering team to provide direction from phase one through phase five of the initiative? Request clear and "protected" assignments through the duration of the initiative and have an approved contingency plan to replace key stakeholders.	Yes	Communicate the desired outcomes and expectations frequently to all stakeholders and identify potential steering team members. When members are replaced, ensure new members receive information that aligns them with ACM program goals.
	No	Work to create legitimate expectations that are in line with the organization's goals. This guide recommends a no-go if they are at odds. Following the reliability culture process is required. Sometimes, a workshop facilitated by a trained, experienced facilitator to thoroughly discuss issues and gain a consensus may resolve objections to allow the program to move forward.

Table 2 – ACM Readiness Factors (Continued)

Readiness Factors	Yes or No	What to Do Next
Does my organization have an up-to-date master equipment list marked up to show criticality and which ACM technologies might apply to each asset?	Yes	Use the list to count the number of assets where each ACM technology may be used and later plan the program and guide implementation in the order of most to least critical.
	No	As needed, create the list, perform criticality analysis and mark each asset on the list to show ACM technology applicability.
Does the organization have sufficient in-house personnel to conduct ACM or can it justify hiring additional staff to permit it?	Yes	Proceed with a plan that uses in-house, recruited additional staff, or a combination of personnel to conduct ACM.
	No	Proceed with a plan to outsource all or part of the ACM effort, making sure the initiatives follow the site plan put together by your ACM team.
Can my organization provide continuity of assignments and consistency of management support over the ACM initiative's life span?	Yes	Document the project's purpose and benefits and reinforce understanding by management and all stakeholders, especially when new management is brought in.
	No	ACM success is highly dependent on management support and focused follow-through. This guide recommends a no-go if support cannot be sustained or if key roles cannot be protected.
Can I demonstrate how the benefits will outweigh the costs? Do my KPIs and cost avoidance/cost savings reports support the initiative?	Yes	Use the cost/benefit information to build support for the project and provide a basis for expected results.
	No	Work with experienced practitioners, production managers and financial staff to clarify opportunities for cost reduction and production increases. If needed, implement new and better measurement tools, with a reasonable estimate of project costs. Using the right metrics will gain the support of executive management to invest in ACM. Sources listed in Section 2.1 provide numerous examples of cost-benefits of ACM.

The decision to initiate an ACM program goes beyond the ACM readiness factors outlined in Table 2. The decision process itself must be designed to initiate an ACM project with enough support to guarantee the resources and follow-through to complete implementation and experience the benefits.

3.2 Identifying the Desired Outcomes

Getting support and buy-in for an ACM initiative requires clearly articulated desired outcomes that are in line with the organization's goals and expectations. Organizations usually identify one or two key outcomes and several desired secondary outcomes. Examples include:

- **Production** – Increased reliability and quality, decreased downtime and increased availability in important systems (i.e., increased production capacity);
- **Cost** – Reduced, avoided, saved, or optimized maintenance costs;
- **Risk** – Reduced probability of failures with environmental, safety, or regulatory consequences;
- **People** – Increased culture of reliability and proactive thinking, cooperation or working knowledge of the system; Involved field personnel have buy-in as to why ACM affects the maintenance tasks they are asked to perform, sometimes on assets that appear to be performing well; A greater understanding is gained of the need for proper execution of those tasks;
- **Documentation** – Maintenance decisions are justified and recorded, enabling future review of why tasks are being performed, with feedback from technicians providing an understanding of the need for action;
- **Optimized List of Critical Spare Parts** – Allows improved inventory management while meeting production and cost outcomes.

Note that ACM cannot increase the inherent reliability of an existing system. Inherent reliability is determined by the initial design and/or subsequent design modifications.

Some practitioners rightfully observe that the need for ACM is driven by the necessity to protect or preserve critical system functions. An organization may find it valuable to identify and assess risks in critical systems. Doing so can help make a case for performing ACM and clarify potential benefits.

Objectives tend to be general statements of intent that have a long-range view without any time limit attached. The question might be: "What are you trying to achieve?"

ACM programs have resulted in significant achievements, including, but not limited to:

- Increase in awareness of and less uncertainty concerning machinery condition, then planning for repair can proceed in an orderly fashion at a reasonable cost;
- Ability to anticipate conditions, which, if unattended, may lead to reduced throughput or a complete failure to produce a product and/or assure its highest required level of quality and value to customers;
- Ability, because of advanced warning of potentially severe problems, to schedule a repair to restore full function at a time chosen, rather than forced action based on asset failure;
- Ability to replace time directed, intrusive inspection preventive maintenance requirements with non-intrusive monitoring requirements that look for the same types of defects, most of which are performed while the machinery continues to operate; This, in turn, results in:
  - Fewer infant mortality failures caused by intrusive inspection actions;
  - Less disruption of production caused by start-ups and shutdowns;
  - Less waste of production materials resulting from start-ups and shutdowns;
  - Increased safety of maintenance and operating personnel.
- More focused repair actions that cost less to perform in terms of labor, replacement parts, consumables and time out of production; This, in turn, results in:
  - Lower overall maintenance costs and cost per unit produced;
  - Less expenditure for overtime pay;
  - More availability of equipment for production;
  - Lower stress levels on personnel and machinery.
- Ability to use the same technologies engaged in monitoring to check on the quality of repairs performed and to establish new baseline performance data for the new operating cycle;
- Ability to detect design weaknesses in equipment which, if corrected by modification, can result in:
  - Longer equipment operating cycles;

- Higher throughput;
- Better quality of product.

Any combination of these achievements may be the objective or motivation for starting and continuing an ACM program. However, an ACM program will be judged on its value, in monetary terms, quickly after its establishment by managers in the organization who must provide and defend the resources needed for it. People are always judged on their results. The great intentions that are listed and voiced early in the process must be backed up with legitimate results.

3.3 Getting Support and Buy-In

Arguably, the most important group from which buy-in is needed is the working level maintenance personnel. Those practitioners who are out there performing the work every day need to be heard and they need to see what's in it for them. One of the ways to gain support of working level maintenance personnel is to show how ACM tasks provide the rationale for reducing their workload. There are at least two ways in which this can occur:

1. When ACM tasks replace preventive maintenance (PM) tasks formerly carried out by maintenance crew personnel and the PM task(s) aimed at detecting the same failure mode are eliminated;
2. When ACM on-condition work orders pinpoint the exact component needing attention well in advance of functional failure, thereby reducing a planned repair to only the work needed to restore function and avoid untimely calls to personnel on weekends, holidays and nights beyond the regular work day.

Making easy to learn and easy to use ACM tools available to maintenance crew personnel and giving them the responsibility and ownership for determining when a repair has been successfully completed is another way in which buy-in can be achieved. This results in these advantages:

1. When maintenance crew personnel can determine an ACM-initiated cause has been resolved during post maintenance testing with *their* tools, it avoids the embarrassment of turning over the asset to operations only to find the repair wasn't successful and having to go back and do it over again.

2. Doing post maintenance testing using their tools allows repair personnel to return assets to operations more quickly than if they had to call an internal ACM team or contractor personnel. This becomes even more important when assets are widely disbursed geographically and/or when ACM specialists are not located locally.

An ACM project requires several essential, well-coordinated roles to prepare, conduct and implement the results. During the planning process, consider the following ACM-specific roles in Table 3 and how they will be supported through internal or external resources throughout the initiative. The roles can be assigned to one or more individuals or teams, depending on the structure of the organization.

For example, an organization may have a reliability engineer who performs many roles, or it may contract some roles out while building internal capability. While some roles do not need to be identified in advance, they should at least be discussed, including expectations for who needs

Table 3 – Defining ACM Initiative Roles and Responsibilities

Role	What They Do	When to Get Firm Commitment	Who Provides Input on Expectations
Sponsor	Selects ACM champion (i.e., executive sponsorship); Sets level of effort; Approves business case recommendations for implementation; Allocates human and monetary resources	Beginning of business case phase	O&M Managers Reliability Engineer and/or Steering Team
ACM Champion	Develops business case and ACM program plan; Owns management of change (i.e., implementation); Selects facilitator; Quality control; Communicates; Measures baseline and results; Monitors for enhancement	Beginning of business case phase	Sponsor O&M Managers Reliability Engineer and/or Steering Team
ACM Facilitator	Assists ACM champion; Mentors ACM team leader; Communicates; Measures baseline and results; Monitors for enhancement; Assists steering and task teams	From beginning of business case phase to no later than beginning of planning and procurement phase	Sponsor Maintenance Manager ACM Champion and/or Steering Team

Table 3 – Defining ACM Initiative Roles and Responsibilities (Continued)

Role	What They Do	When to Get Firm Commitment	Who Provides Input on Expectations
ACM Team Leader	Assists ACM champion; Executes ACM plan; Assists in recruiting; Oversees training and certification of ACM team members and maintenance crew practitioners	Beginning of plan and procurement phase	ACM Champion O&M Managers and/or Steering Team
Maintenance Manager	Nominates candidate(s) to be ACM champion; Assists in developing business case for ACM ——— Commits in-house personnel or initiates hiring additional technician(s) and/or contractor resource(s) to execute ACM initiative; Serves on steering team	Beginning of business case phase ——— Beginning of plan and procurement phase	Maintenance Crew Leaders ACM Team Leader ACM Champion and/or ACM Steering Team
Operations Manager	Commits operator resource(s) to assuring the best possible outcome; Serves on steering team	Beginning of business case phase as steering team member	First-Line Operations Supervisors
Reliability Manager or Lead Engineer	Supports ACM champion and maintenance manager; Serves on steering team	Beginning of business case phase as steering team member	O&M Managers or ACM Steering Team
ACM Technicians	Execute responsibilities listed in Section 6.2 of this guide	Upon assignment to the ACM position	ACM Team Leader
ACM Practitioners	Execute responsibilities listed in Section 6.2 of this guide	Upon assignment to support the ACM initiative	Maintenance Crew Leaders

to provide input, who makes decisions and who is accountable to make sure commitments are made and carried out. Table 3 is a reference to help organizations assign the right roles and expectations at the right time.

Remember, these roles and responsibilities may overlap, depending on the size of the organization and the amount of work required to reach the goals and objectives of the ACM team.

3.4 ACM Program Framework Options

Recent developments in the field of asset condition monitoring have led to the recognition of a hierarchy of organizational arrangements or frameworks to construct the most capable, risk mitigating and sustainable program. This is illustrated in Figure 8.

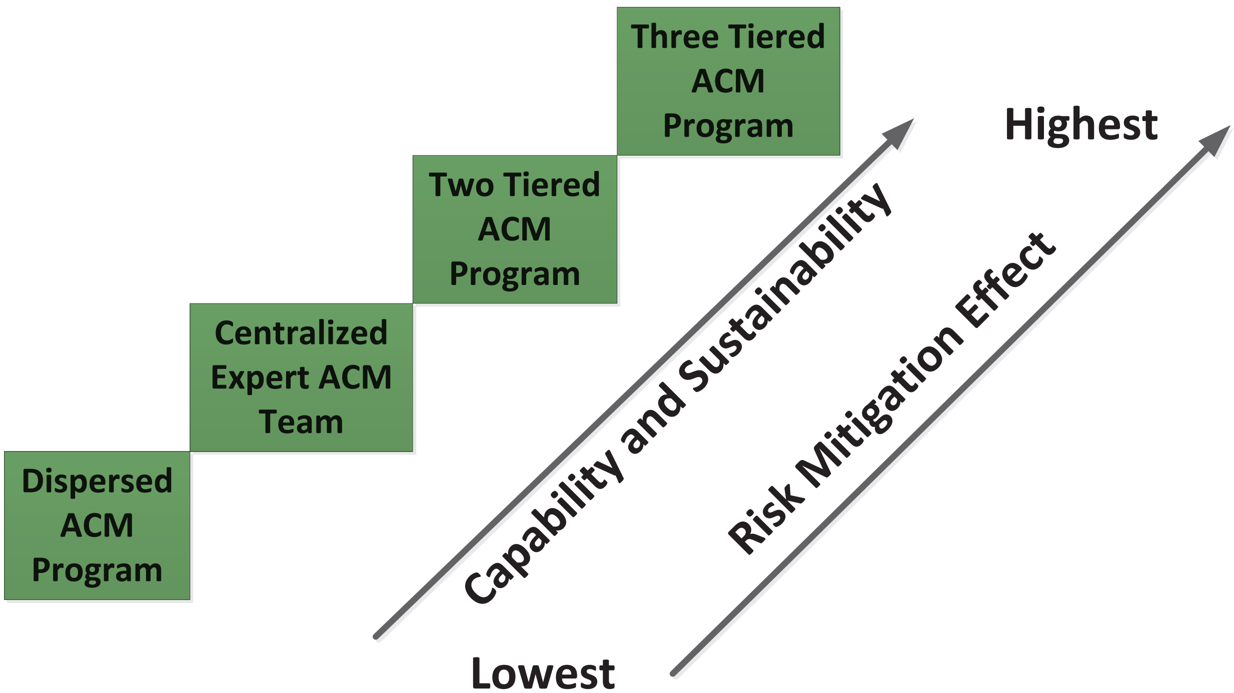


Figure 8: ACM/PdM program structure capability, sustainability and risk mitigation effects

Most asset condition monitoring programs employ a stand-alone or a one tier centralized or decentralized configuration. Offerings of low-cost instruments now make it possible to equip maintenance and/or operations personnel with limited capability monitoring and diagnosis tools. This involves using vibration, ultrasonic, thermographic and other technologies to indicate the presence or absence of abnormal, but non-specific, conditions in all types of utility, manufacturing, commercial and mobile assets. Small plants with few personnel involved with maintenance may be able to only accommodate and use the simple, easy to learn ACM tools. The guiding principle here is that **it is better to have *some* ACM than *no* ACM**.

A two tiered ACM program in larger organizations may have both centralized and decentralized components internally. The centralized component usually consists of a co-located team of technicians. The number of required personnel depends on the number of assets monitored, their proximity to each other and the team office, and travel time between them. In more advanced programs where data are transmitted to a central office rather than collected manually in the field, the number of ACM analysts is lower than if they also had to collect data. Each team member is trained and certified in one predictive technology initially, then in additional technologies as time and talent permit to do in-depth diagnostic and prognostic analyses. This cross-training of your ACM team enhances the skill sets and overall success of the team.

The decentralized component of the ACM program involves maintenance and/or operations practitioners who receive training and support from more highly trained and certified team members or commercial trainers. Practitioners are trained to use easy to learn and easy to apply, but limited capability, predictive technology instruments. These tools also may be used by the same personnel to conduct post maintenance testing after problem correction and reassembly. Follow-up reports showing successful remedies to condition monitoring work orders give credence to the ACM initiative and assures support going forward with the program. Figure 9 illustrates a two tiered ACM program framework.

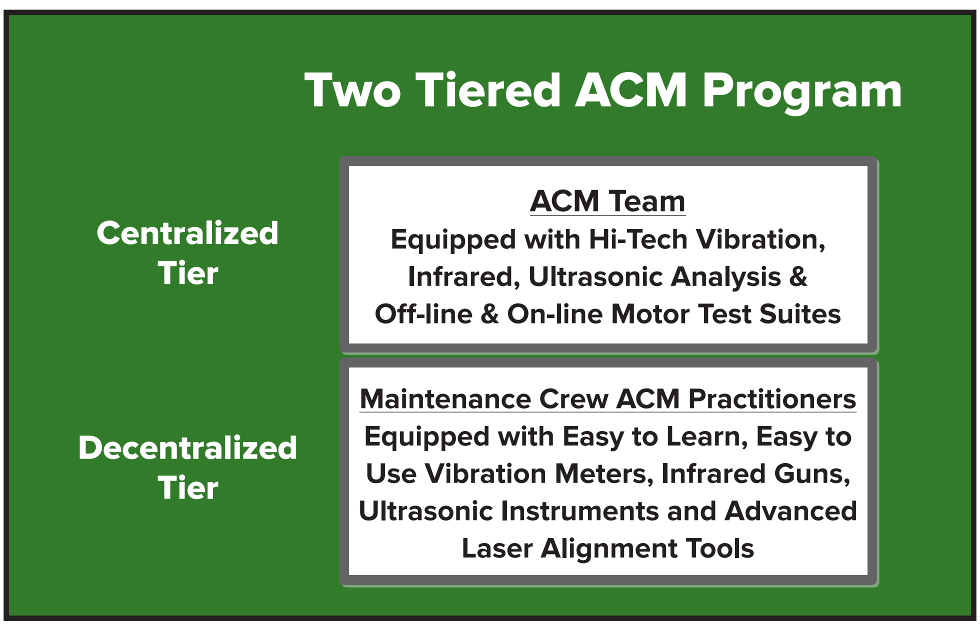


Figure 9: Two tiered ACM program

Another second or third tier of a multi-tiered program involves the use of highly skilled outside contractors or consultants to back up internal ACM program personnel, either on a continuous, part-time or on request basis. They may provide support on-site and/or remotely. Figure 10 illustrates a three tiered ACM program framework.

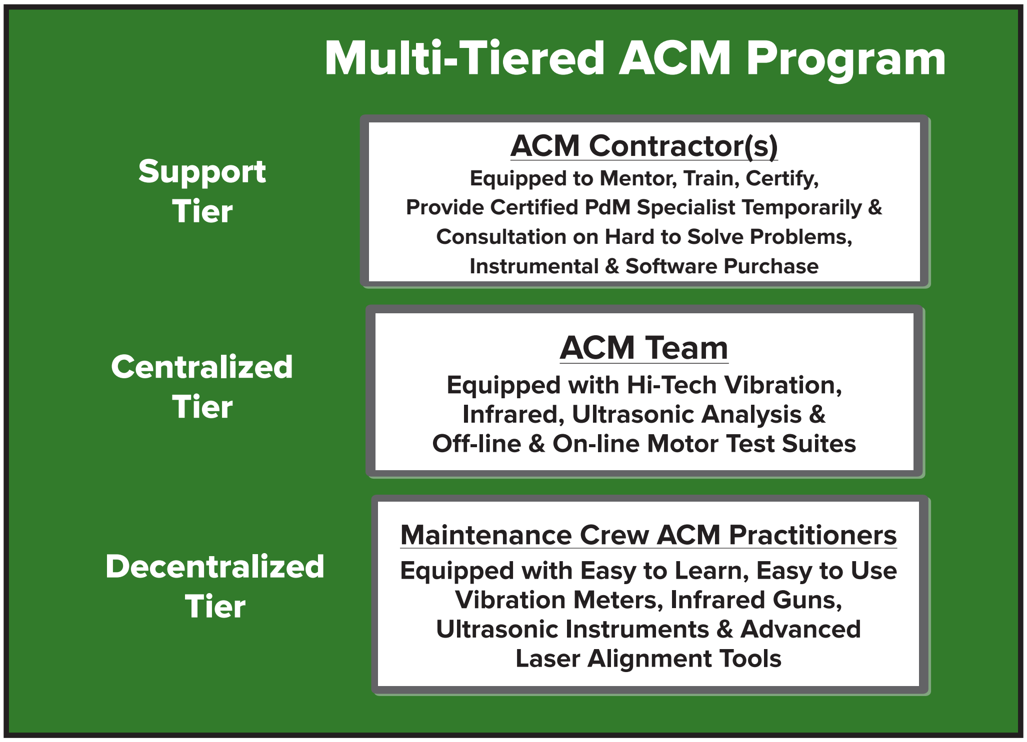


Figure 10: Multi-tiered ACM program

Variations of these frameworks also may be employed. For example, the ACM team may be outsourced or provided by contractor(s). One particularly effective ACM program implemented by TimkenSteel Company had contractors operating from assigned offices in one of their three plants in Canton, Ohio, rather than from the contractor's offices. Ultimately, the program was so successful that TimkenSteel bought the ACM division from the contractor and internalized its employees permanently as a team into its workforce. A less capable, lower tier practitioner was never established because the team was able to cover all functions of the ACM program so effectively.

Another variation may include lubrication and wear particle analysis management and related lubrication program tasks. Certainly, results of analyses are valuable in assessing the condition of assets as completely as possible and should be made available to ACM team members in making their recommendations.

The tier of a multi-tiered ACM program that involves outside contractor(s) will ultimately include one or more service providers linked by wireless and other networks to the Industrial Internet of Things (IIoT) for big data management in the Cloud and the application of advanced analytics conducted far from the assets being monitored. Such a multi-tiered arrangement would look something like what is depicted in Figure 11.

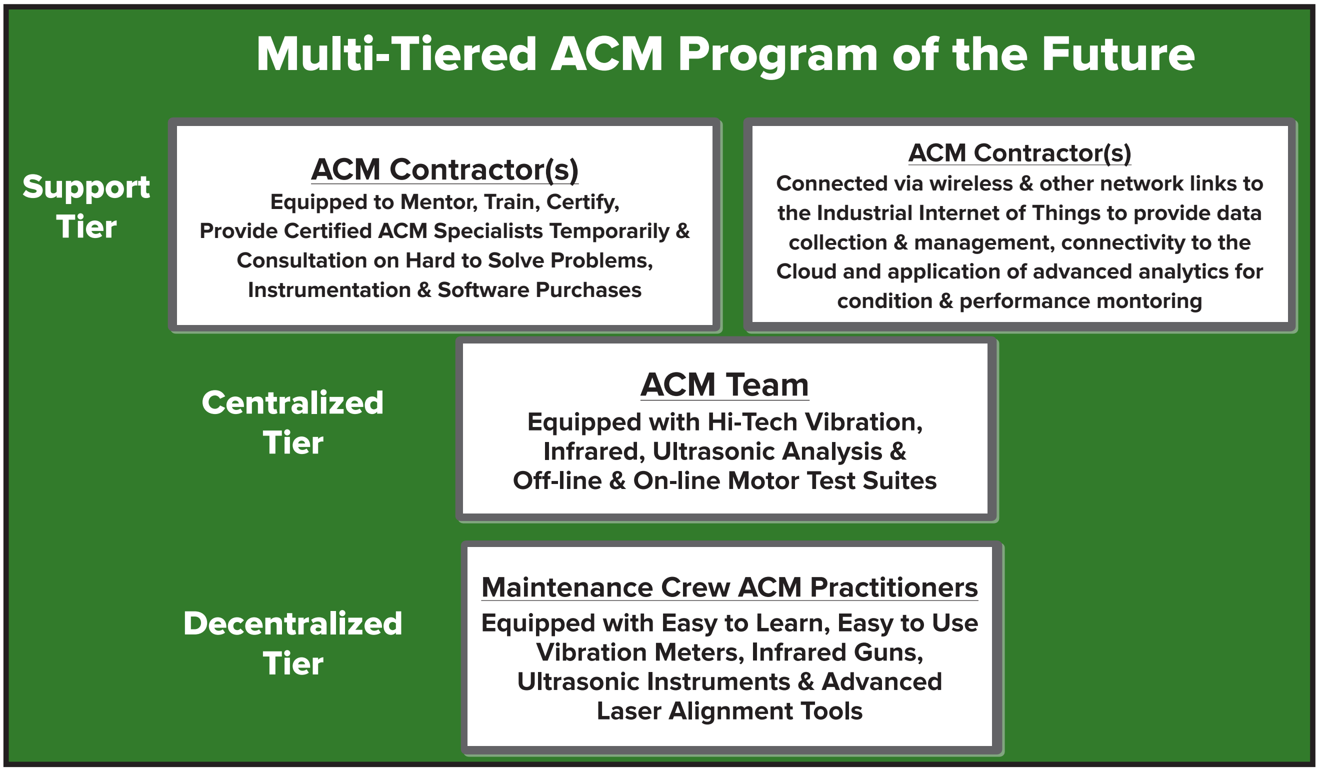


Figure 11: Multi-tiered ACM program of the future

Personnel responsibilities in the centralized and decentralized tier might change as confidence in the support tier providing remote monitoring grows. This might involve adding more technologies, moving such tasks as baseline data collection and post maintenance testing from the centralized to the decentralized tier (or vice versa) or eliminating one of the lower tiers and combining their functions.

Whichever program you choose, be aware that you may have to change and adjust how you are deploying the program after your KPIs and other metrics expose how you are performing in relation to your goals and objectives.

3.5 Risk Factors to Mitigate and Pitfalls to Avoid

If your organization has an established contractor provided ACM program that you want to bring in-house, it should be done only after careful analysis of expected benefits and problems that are likely to be encountered. For example, it takes a long time for novice ACM technicians to become proficient in some technologies, particularly vibration analysis, infrared thermography, and off-line and on-line motor circuit analysis. Other technologies, such as ultrasonic analysis, may be easier to learn. Actually, having a competent ACM contractor already engaged with assets makes the transition to an in-house program easier and quicker if the contractor is willing and able to train and mentor in-house personnel in the technologies already being applied. If the contractor has Level III specialists who have developed written exams that meet the requirements of a professional society certification program, they also can help with certification in their specialty areas, if that is important to an organization.

Use caution here. It should be noted, and many ACM services contractors will attest to this, that most attempts to bring an ACM program in-house have a high chance of failure. This is because of internal factors. When your ACM program encounters these pitfalls, this is when the executive sponsorship must step up, make the appropriate adjustments and show support to get to the long-term goals set by the ACM steering committee. In general, pitfalls applying to all ACM programs include, but are not limited to, those listed in Table 4. In addition, best practices to mitigate the risk or avoid the pitfall are listed beside each entry.

Table 4 – Risk Factors to Mitigate and Pitfalls to Avoid and What to Do About Them

Risk Factor or Pitfall	What to Do (Best Practice) to Mitigate or Avoid
Candidates selected for ACM teams lack computer literacy	Write ACM team member position descriptions that mandate and test computer literacy (e.g., in CMMS work order writing and reporting finds) as a prerequisite for application
Inability of ACM team candidates to excel in complex ACM technologies and pass certification exams	Write into position descriptions all reasonable technical requirements and courses that must be attended and certification obtained; Set time limits for all technologies to be assigned and levels of competency that must be achieved; Setting expectations shows support and encourages ownership by practitioners
Lack of appreciation by managers, supervisors, team candidates and coworkers of the difficulty in achieving competency in complex ACM technology, resulting in reduction in capability expectations or change to an outsourced program	Include a summary of requirements in manager and supervisor ACM orientation briefings, especially for new managers; See recommendations above and below for team candidates and coworkers

Table 4 – Risk Factors to Mitigate and Pitfalls to Avoid and What to Do About Them (Continued)	
Risk Factor or Pitfall	**What to Do (Best Practice) to Mitigate or Avoid**
Failure of managers and coworkers to appreciate that while a portion of an ACM technician's work is done in an air-conditioned, comfortable, office-like setting in front of a computer and much of the rest in the field using fancy electronic packages rather than wrenches, hammers and screwdrivers, the job is every bit as demanding as those of maintenance crew personnel	Stress benefits of ACM to all; Positions may be classified differently than ordinary maintenance technicians with different pay scales; Union seniority rules may have to be negotiated to avoid placing unqualified candidates in ACM positions, resulting in embarrassment and program ineffectiveness
Organizational culture does not embrace change or lacks support mechanism for incorporating change on a permanent basis, resulting in bureaucratic elasticity – returning to the status before the attempt to establish or upgrade an ACM program	Develop a credible ACM master plan and get support for it at the executive level that will make it stick; Communicate benefits to all once program starts
Failure to create and maintain current the ACM program master plan	Change plan as needed – every quarter the first year, 2 times second year and annually thereafter is not uncommon
Failure to establish and defend over the long-term an adequate budget for all aspects of the ACM program	Include rolling 5-year budget in plan and schedule plan update 2 to 3 months before annual call for budget inputs
Failure to provide resources for modifying assets to make ACM data collection safer and more productive	Include requirements in plan, along with full justification; Review and update each year as needed
Failure to educate and orient management, supervisors and coworkers of the benefits of an ACM program to them, both collectively and individually	Regular dates for program updates to leadership are very important; Communicate, communicate, communicate to constantly reinforce ACM benefits to incumbents and indoctrinate new employees at all levels
Failure to continuously calculate financial justification (i.e., return on investment) and document other tangible and intangible benefits of an ACM program to show its true worth year after year	Properly define and enforce monetary and other KPI(s) continuously without fail each year; See Section 5.4 of this guide
Failure to keep sponsor, champion(s) and other stakeholders current on the progress of the project and/or selection of inadequate report elements (e.g., no meaningful metrics)	Monitor and act on the KPIs that reflect the organization's goals and objectives; Track implementation progress and communicate, communicate, communicate!
Failure to provide for retention of ACM technicians after they become competent in assigned technologies	Provide wage differential(s) for personnel who achieve various levels of certification
Failure to establish a succession scheme for ACM team personnel who retire or move on to jobs having greater responsibility and incentives	Develop a proactive succession strategy; Identify and prequalify; Train and support certification of candidates from in-house staff to replace ACM team members, allowing time for experienced personnel to mentor new people

The last item is particularly important. If ideal (i.e., best and brightest) candidates are selected for an ACM team, management must expect that sooner or later some of them will move on to better paying, higher level positions. Ideally, this will be within the current organization, where they should become proponents of ACM. In the worst case, they leave with only a two-week notice and go elsewhere. It then takes months to identify novice candidates or hire partially experienced or even certified replacements and get them up to speed. In the meantime, monitoring languishes, reliability may decline and, if true worth hasn't been documented, the ACM program may be abandoned. This can result in a decline in availability while the maintenance strategy reverts to costlier approaches, such as reactive maintenance.

To mitigate this risk, an organization that wants a vigorous ACM program should continue its relationship with an ACM contractor to support the program in areas needed and when required. This might involve, for example, establishing contingency contracts with selected vendors that can be activated on short notice for services. One provision might be to provide certified replacements on a short-term basis to fill vacant slots while a new team member is reassigned from another part of the organization or hired from outside. If the new person is already competent in the lead technology, the contractor can depart after turnover. If not, the contractor may stay on to mentor the new incumbent until the individual is ready to assume enough of the job to be effective.

If a two tiered ACM program is in effect, candidates from the lower tier already involved with simpler tools who express interest and aptitude for more knowledge of the subject may be given the opportunity to serve part-time with certified or fully competent ACM specialists, fill in for them when needed and ultimately be preselected as permanent replacements when the incumbents move on.

Another pitfall to avoid is deciding that an ACM program can be done on the cheap when available resources for a fully capable program should have been allocated. For example, simpler, easy to learn ACM technology tools are acquired, but more sophisticated suites are never applied, even with contractor support. In such cases, the diagnostic and long-term analysis capabilities of advanced ACM software and the full potential of a comprehensive ACM program *won't* be realized.

Similarly, sophisticated and costly ACM tools are acquired and put in the hands of maintenance crew personnel who were given training but:

a. Didn't apply what was taught soon after the classes so they lost the benefit of them;

b. Had too few opportunities in small plants with few assets to learn on the job how to apply them;

c. Were transferred or assigned to other duties that don't include using the tools for which they had been trained.

In choosing an ACM mentoring organization, it is important, but not absolutely essential, that advanced technology hardware and software suites that mentors are familiar with are as close as possible to what will be acquired for use by the in-house team. Most larger companies will choose to standardize on a name brand and software to keep training, system support and competency levels consistent. This is especially true for vibration analysis and motor testing, but less so for infrared thermography and ultrasonic analysis. Familiarity simplifies the mentoring process by directing learning to the team, rather than requiring it of both parties.

Consultations with contractor(s) currently providing ACM monitoring services may help in the quest to select the right vibration, infrared thermography and other technology suites for in-house programs. As a general rule, monitoring contractors select for their own use those packages that are the most productive and efficient in meeting both their needs and those of their customers. They also may be able to help by providing insight on how well high-end hardware and software vendors are at providing post sale customer support, an important factor at all stages of development of an in-house ACM program. However, training and certification requirements are generally vendor neutral for ACM technologies addressed by professional organizations, such as ASNT, ICML or the Vibration Institute.

4.0 USING STEERING AND TASK TEAMS TO SCOPE AND PLAN AN ACM INITIATIVE

One effective ACM initiative approach involves forming teams to commit to a project using a formal charter process. The book, *Why Execution Fails and What to Do About It* (see Section 7.1 References), offers examples of simple steering and task team charter templates that can adapt to any organization. The chartering process can be simple and fast, or expanded to increase the level of involvement necessary for success. An organization may benefit from an expanded, involvement-driven process if the culture is not accustomed to change, or struggles with discipline or structure. To maximize involvement, the organization may want to engage a chartering facilitator who specializes in the area of organizational development or leadership. A facilitator's methodologies can dramatically increase cultural acceptance.

The charter/contract should include baseline reliability measures so the organization can compare past performance to present levels once the ACM business case recommendations are implemented and performed. Top management should receive an executive overview of ACM principles and the reliability benefits that accrue from it.

In the case of ACM start-up or major restructuring initiatives, members of the steering team may include, at various times:

- Operations and/or Production Manager;
- Maintenance Manager;
- Reliability Manager or Lead Engineer;
- Information Technology Manager;
- Procurement and/or Contracts Manager;
- Executive (e.g., Plant Manager) to whom each of the above reports directly or through one of the above *and* has final decision and resource allocation responsibility;
- Designated ACM Program Champion who, for purposes of the project, reports to the responsible executive and aggregates information into a coherent consensus business case.

The plan development and procurement stage for an ACM start-up or major restructuring usually requires a different knowledge base, set of skills and time commitment than that available from steering team members. The steering team continues its involvement as indicated in Figure 3 to provide oversight through the plan development, implementation, procurement and integration, and benefits stages up to the point where success of the initiative is assured. The responsible executive should direct steering team members to identify personnel for one or more task teams under the leadership of the ACM program champion. In the case of ACM start-up or restructuring projects, task teams may be formed for these purposes:

- Writing ACM program position descriptions and interviewing and rating candidates;
- Identifying working space, office and field equipment requirements for conducting ACM activities and initiating required paperwork to secure space(s) and equipment needed to support the ACM option selected by the responsible executive;
- Writing the ACM plan, which will be needed regardless of whether outside contractors or in-house personnel are used exclusively or a combination of human resources is employed in ACM;
- Identifying candidate vendors for the ACM technology hardware, software and supporting services;
- Preparing requests for proposals for acquisition of hardware, software and contractor services and/or using purchase authority to procure ACM assets, training in their use and certification exams.

The makeup of the task team is dictated by the nature and requirements of the task(s) assigned, as well as the human resources skills available in an organization. For example, preparation of ACM position descriptions could include a person from the organization's human resources department who is experienced in writing such documents. Technical details might be provided by the designated ACM program champion and the supervisor (e.g., the maintenance manager) under which the ACM team would function in an organization. Everybody would work as a group to interview candidates and provide their evaluations to the company official who makes hiring or internal reassignment decisions.

If the decision is made to contract some or all ACM services, then requests for proposal (RFP), eventual contract specifications and terms and conditions must be prepared. In this case, a task team consisting of the ACM project champion and a contract specialist would be appropriate. In any case, always maintain ownership of the program with an on-site, top level management person to assure the site's ACM goals and objectives are always a priority.

Office space requirements might be arranged between the ACM program champion and the facilities manager or other person(s) responsible for allocating and equipping such assets to in-house personnel or contractors hired to perform and report upon ACM findings.

The ACM program champion and the direct reporting senior for the ACM team might collaborate to write the ACM plan. They also might team up to evaluate potential vendors of ACM hardware and software suites and initiate procurement requests for the items selected. If a program restructuring is planned, the process for transition should be described. For example, if the plan is to bring an existing ACM effort in-house, modifying existing contracts to provide for contractor experts to mentor in-house personnel might be needed. Conversely, if all or part of a program is to be outsourced, the plan should account for reassignment of in-house personnel and a smooth transition by having them assist incoming contractor experts in locating and gaining access to assets to be monitored.

5.0 IMPLEMENTING THE ACM INITIATIVE AND REPORTING PROGRESS

Like reliability-centered maintenance (RCM) efforts, implementation is the hard part of an ACM initiative. Close attention must be paid to all the details. Personnel must be attuned to lessons learned and be ready to adjust the plan when needed. Examples of implementation progress report formats are provided and may be useful for projects requiring significant effort. During ACM initiative implementation, benefits begin to emerge almost immediately. Project leaders must be prepared to capture and report them to all involved in order to keep momentum and enthusiasm high and suppress adverse opinions of the project by its detractors. As discussed in Section 2.4, some metrics may move in the wrong direction at first as early ACM finds typically result in added workload and repairs are made to bring the asset up to designed-in reliability. Most of these can be anticipated, but they must be explained and tracked at least to the point where desirable trends are achieved or stabilized at ideal levels.

5.1 Implementation Basics

Implementing an ACM initiative involves the coordination of many different parties, including maintenance management, operations, safety, procurement and/or contracts, stores, information technology, training and/or human resources, planning/scheduling and craftspeople. Some of the required activities include:

- Compilation of ACM tasks into craft or trade specific jobs or time intervals (referred to as task packaging or maintenance task optimization);
- Identification of required maintenance and operations task resources (e.g., money, time, personnel);
- Coordination with governing authorities, audits, regulations, safety concerns, or other parties affected;
- Procedure writing, route or rounds lists, schedule development, walk down and approval;
- Asset tagging, marking or data collection point identification and data requirement development;
- Modification of assets to accommodate ACM (e.g., installing lubrication sample collection apparatus, low voltage electrical panels in motor control centers for on-line analysis, infrared windows in electrical distribution panels, wireless or remotely wired transducers for safely collecting vibration data or routing it to network gateways for remote analysis);

- Procurement of special tools, parts and consumables needed to carry out the ACM procedures mandated by the maintenance strategy;
- Training, or at least orientation, on the new procedures for those who are to perform and support them, including maintenance, operations, planning, scheduling, stores and purchasing;
- Planning and scheduling of new ACM-based procedures and route lists and schedules;
- Data entry into the computerized maintenance management system (CMMS) or enterprise asset management (EAM) system and aligning all asset identification listings with those in asset condition monitoring management software (ACMMS);
- Initial first-time execution on the system that is the subject of the ACM project in order to establish baselines for monitoring.

NOTES

1. ISO14224:2016 provides compliant equipment hierarchy for both CMMS and ACMMS, which makes implementation much easier. If an organization has a standard hierarchy supported by RCM software, the failure modes and mitigating tasks will align more easily with the CMMS if both use the ISO standard. Although the ISO14224 document is aimed at the oil and gas industry, it can be easily adapted to almost any operation with little effort.
2. If ACM requirements are the result of a properly done RCM project, the results should be a proactive ACM with a technology-focused set of tasks that are more effectively linked to failure modes. The trick is to preserve the connection as RCM derived tasks are combined and modified later with changes to both asset inventories and other factors.

ACM implementation may seem like a complex project unto itself. Successful implementation requires a detailed implementation plan that is temporary and separate, but linked to the ACM master plan. The implementation plan should list what must be done, who is responsible for doing it and when the work must be completed.

The implementation plan is ready for execution when all those involved in authorizing change, committing resources and carrying out activities, including the overall maintenance strategy, fully understand and agree to carry it out. If an organization has an established management of change procedure, take maximum advantage of it.

5.2 Implementation Tracking

Implementation-focused metrics provide measures that signify progress toward implementing an ACM initiative. For example, using numbers identified during the analysis phase of an RCM project as a basis, the metrics concentrate on the number and percentage of each task category that has been fully implemented (e.g., new on-condition task, modified task, cancellation of specified old program tasks, design modifications, operational procedure changes, etc.).

Organizations with multiple RCM efforts in progress or in concurrent implementation may need a way to track the status of each and the teams responsible for completing the work. An organization may elect to break out the status report by task type (e.g., time directed or PM, condition directed or PdM, failure finding or operator or craft). There is also the option to track the number of tasks implemented compared to the number identified in an RCM study report, as well as the percent completed. See Reference #8 in Section 7.1 for RCM implementation tracking report formats.

If the driving force for an ACM initiative **doesn't** involve RCM, total productive maintenance (TPM), or other proven methodologies for task identification, then a "ramped, intuitive" rather than "targeted" approach to implementation may be required. In a ramped, intuitive approach, ACM technicians are instructed to use their knowledge of failure history on common assets to build a list of data collection points to monitor. Ideally, if criticality rankings are available, the listing of monitored points will start with the most critical assets and work down the list from there. Or, the organization may identify "bad actors" using Pareto analysis and start implementation by applying the 80/20 rule.

Table 5 provides an example of an ACM implementation status report.

Table 5 – ACM Implementation Status Report: Percent Implemented by Technology

Technology	# of Assets to Which Applicable	% of Assets Upon Which ACM Implemented	% of Assets Requiring Maintenance Task Optimization
Vibration Analysis			
Infrared Thermography			
Ultrasonic Analysis			
Off-Line Motor Circuit Analysis			

Table 5 – ACM Implementation Status Report: Percent Implemented by Technology (Continued)			
Technology	**# of Assets to Which Applicable**	**% of Assets Upon Which ACM Implemented**	**% of Assets Requiring Maintenance Task Optimization**
On-Line Motor Circuit Analysis			
Lubricant & Wear Particle Analysis			
Laser Alignment			
Transformer Condition Monitoring			

An organization may wish to measure the effort being put into implementation work. For example, Table 6 tracks the effort expended to date. This report is useful in determining whether or not an initiative is getting the attention needed for success. If, for example, the number or percentage of assets being included during the initiative's implementation isn't increasing and the number of labor hours being expended isn't changing, then an inquiry should be made as to why and what to do about it.

Table 6 – ACM Initiative Implementation Labor Hours Metrics		
Labor Hours By:	**Last Report (Date) Hours**	**This Report (Date) Hours**
Management		
Maintenance, Operations and Engineering Personnel, including training and/or orientation		
Support Personnel, including procurement, contractors and any others involved directly in implementation		
Total labor hours expended to implement ACM initiative tasks		

5.3 Measuring the Benefits and Impact of an ACM Initiative

An ACM initiative supports and improves the living reliability program. Organizations should measure benefits relative to the pre-initiative baseline to assess the effectiveness of ACM task implementation. Start measuring immediately after implementation begins and continue indefinitely. The time period(s) used will vary based on the type of measure and the quality and availability of the data. The ultimate goal is to achieve permanency so discontinuing ACM would be unthinkable and no one would want to go back to pre-ACM days.

ACM will improve performance by decreasing downtime because it reduces mean time to repair (MTTR) by finding defects earlier in their development, thereby allowing for proper planning and scheduling at a time the organization is best prepared to perform the repair most effectively. In addition, repairs done in a timely fashion limit the potential for collateral damage and the need to correct that, too. Longer mean time between failures (MTBF) is made possible when post maintenance testing using an ACM technology detects the degradation and the associated work order confirms the quality of the repairs.

Improving reliability and lowering maintenance costs, along with several of the other measures listed in this guide, are very realistic goals. Once a system achieves its inherent designed reliability, the best an organization can do is sustain that level of reliability. Even after creating a maintenance strategy based on RCM, the most effective methodology ever established for that purpose, subsequent events may dictate a change to that strategy. Tweaking task frequencies or adding new ACM technologies and tasks to detect previously unidentified failure modes are common actions to further improve performance and restore reliability to its inherent designed-in limit.

A useful presentation may consist of a set of graphs with the metric(s) plotted against time and clearly showing the point where implementation began. The periods selected should be representative of what is considered the “normal” operating profile for the asset being evaluated. Trends will then be evident and referenced to a definite point in operating time when the positive results of the ACM initiative begin to emerge. These metrics must be presented in a broader context since many *other* initiatives may affect them during the same period of time as the phases of an ACM initiative.

Only a few of the metrics in this guide may be meaningful to an organization. It also may have other metrics specific to its needs that this guide does not contain. As few as six or eight metrics may be all that are needed to make the case for an ACM initiative and determine benefits derived from it. Metrics should be collected on the systems to which ACM is applied and studied prior to the decision to proceed. After a sufficient period of time, they will provide a true comparison of before and after performance. A partial list of metrics that should be considered and desirable trends after implementation of an ACM initiative are provided in Table 7.

Table 7 – ACM Impact on Metrics and Trends Relative to Baseline

Metric Impacted	Desired Trend Direction & Target (if applicable)
Safety incidents for staff involved with a system to which ACM is applied	Down, Target: Zero
Throughput or output potential due to increased availability of assets	Up
Yield or capacity factor	Up
Scrap rate and product quality	Down
Heat rate	Down
Quality rate	Up
Rework rate	Down
PM labor hours as a percentage of total maintenance labor hours performed (see Notes: #1)	Down
PM compliance after removal of PMs and replacement by ACM tasks	Up
On-condition or condition directed maintenance as a percentage of total maintenance labor hours, including all labor hours for restoring abnormal conditions found (see Notes: #2)	Up
Total cost to perform an ACM-based maintenance program (see Notes: #3)	Down
Overall equipment effectiveness (see Notes: #2)	Up
Total effective equipment performance	Up
Failure (forced outage) rate	Down
Corrective maintenance events (see Notes: #4)	Down
System availability or overall equipment availability	Up
System reliability or overall equipment reliability	Up
System or overall equipment MTTR	Down
Emergency/demand maintenance labor hours as a percentage of total maintenance labor hours (see Notes: #1 and #3)	Down
Overtime labor hours by maintenance personnel as a percentage of total maintenance labor hours (see Notes: #1)	Down
Lost profit opportunities	Down
Corrective maintenance labor hours as a percentage of total maintenance labor hours (see Notes: #1 and Definition 2 in Section 7.2 - Glossary)	Down
Hours of unscheduled downtime (see Notes: #2)	Down
Hours of scheduled downtime	Down
Total cost to perform maintenance and for the whole facility (see Notes: #2)	Down
Total cost of replacement parts for a representative period	Down
Total cost of consumables	Down

NOTES

1. Where a metric involves labor hours, it may be useful to break out subsets by trade category (e.g., electrical, mechanical, etc.).
2. Maintenance labor hour expenditures described in this guide do not include those labor hours expended by operators who perform PM and condition monitoring tasks as part of their job responsibilities.
3. It has been useful in some instances to distinguish between labor hours and replacement parts costs for repair of the primary system separately from collateral damage costs to secondary systems.
4. Specifically, those events that occurred after functional failure. See corrective maintenance definition in Section 7.2.

Comparative measures are not possible when performing ACM on a new system with no available history or maintenance plans. In this case, use the established measures to confirm that system performance is sustained at desired levels.

Some chronic problems may not yield to an ACM-based solution or other methodologies, such as root cause failure analysis follow-up actions. This is where severe problem-solving teams, like Six Sigma, can really add to the total team's success. It may be useful to report metrics, such as failure rates, on these items separately or with caveats explaining the situation.

5.4 Key Performance Indicators for Asset Condition Monitoring

It is important to keep current on the status of the asset condition monitoring program's effectiveness and return on investment (ROI). Reference #1 in Section 7.1 provides an in-depth discussion on a variety of ACM program metrics, including these two very important ones. It describes how to document them in an annex of the ACM master plan and provides in-depth examples using the following outline for each.

- KPI Title
- Purpose and Benefit

- Definition
- Explanation and Usage
- Formula(s)
- Definition of Each Component in the Formula(s)
- Qualification(s) – for example – to which asset(s) the KPI applies, limits of comparisons between plants, how often to calculate and how to interpret trends.
- Sample Calculation(s)

This section provides greater detail on the two KPIs previously mentioned: ACM program effectiveness and ROI. Each requires that work done as a result of an asset condition monitoring or predictive maintenance find is reflected in a specific type of work order designated in the CMMS or enterprise resource planning (ERP) system as a predictive maintenance repair (PDMR) and is distinguishable from other types of work orders (e.g., preventive maintenance repair (PMR), corrective maintenance (CM) that is unexpected and unplanned, or special project (SP), such as a non-maintenance work order executed by maintenance personnel).

KPI TITLE: ACM PROGRAM EFFECTIVENESS

Purpose and Benefit

When an ACM or PdM find occurs requiring a repair, an asset condition monitoring repair (ACMR) or PDMR work order (WO) is initiated. Should a complete functional failure occur that was *not* detected and reported by a PDMR during the incipient stage using an ACM technology or the associated visual inspection conducted by an ACM team or maintenance crew ACM practitioners, a corrective maintenance (CM WO) is issued. One measure of the effectiveness of an ACM program is its impact on overall health or restoration to health of an asset and a comparison to a base year, in this case 2011, before restructuring from an outsourced to an in-house two tiered ACM program.

NOTE

The terms asset condition monitoring repair (ACMR) and predictive maintenance repair (PDMR) mean the same thing as used in the rest of this guide.

Definition

This KPI is calculated by dividing the number of PDMR WOs by the total of CM WOs **plus** PDMR WOs for one to up to all assets included in the ACM program for specific periods of time, expressed as a percentage. The KPI management tool tabulates the numbers of PDMR and CM WOs continuously. For assets subject to ACM, the number of PDMR WOs should be high relative to CM WOs. The results are more meaningful for larger groups of assets (e.g., for a whole plant or major system with many assets subject to ACM). These values can range from zero percent (i.e., an ACM program has been ineffective; one or more CM WOs, but zero PDMRs or the asset has been without failures and is highly reliable; zero CM WOs and zero PDMRs) to one hundred percent (i.e., ACM program has been highly effective; zero CM WOs and one or more PDMR WOs). Results may be tabulated for individual assets that are prone to failure or larger groups of ACM monitored assets for whole plants and for all plants together.

Explanation and Usage

The ACM program effectiveness KPI allows one to evaluate the effectiveness of an ACM program relative to reactive elements under the strategy for specific assets, as well as for any group up to all assets subject to ACM. Where the ACM program is found to have a low effectiveness rate, an inquiry should be made as to what should be done to make it more effective, taking into account asset criticality and cost to repair. Elements of each component of this KPI can be viewed in the KPI management software and the actual KPI calculated with the formula indicated.

Formulas

$$\text{KPI} = \left(\frac{\text{Component 1}}{\text{Component 2}}\right) \text{x } 100 = \text{Expressed as a percentage}$$

$$\text{Metric} = \text{Component 3} - \text{Component 4}$$
$$= \text{Percent increase or decrease in ACM program effectiveness}$$

Component Definitions

Component 1	Number of PDMR WOs issued in a specific period for an asset or group of assets subject to ACM/PdM
Component 2	Total of all CM and PDMR WOs issued for a specific period for an asset or group of assets subject to ACM/PdM
Component 3	Asset condition monitoring program effectiveness for last complete year
Component 4	Asset condition monitoring program effectiveness for 2011 or year previous to any complete year after 2011

Qualifications

- The ACM program's effectiveness should be measured annually for those assets subject to ACM program application.
- It may take several years for this KPI to be meaningful for individual assets or small groups of assets.
- The KPI is dependent on the CMMS and KPI management tool being able to distinguish assets subject to ACM from all assets of a system or plant, and distinguish ACM program initiated WOs from WOs initiated without ACM program involvement.

Sample Calculation

Number of PDMRs issued in 2013 for an asset group = 10

Number of CM work orders issued for the same machine group during the above period = 2

ACM program effectiveness for this machine group 10/10 + 2 = .83%

KPI TITLE: ACM PROGRAM ROI

Purpose and Benefit

Return on investment of the ACM program reflects only one measure of its value, which is based exclusively on maintenance costs avoided and/or saved. There are many other reasons for investing in asset condition monitoring, including, but not limited to:

- Avoiding unanticipated loss of capacity and production by early detection of degraded conditions in assets subject to ACM;
- Maintaining quality of the environment;
- Avoiding major failures that could threaten safety of in-house and nearby personnel.

Definition

The ACM program ROI is the value of Component 1, divided by Component 2, expressed as a dimensionless ratio. The desired range is greater than one. It should be calculated annually at the end of each fiscal year. It is calculated for the whole program (i.e., for all plants together) and not by individual plants. Accuracy is determined by the ability of maintenance crew leaders to estimate, based on historical data, if possible, the cost of restoration had the asset been allowed to run to complete failure.

Explanation and Usage

This ACM program ROI allows interested parties to gain one measure of the value of an ACM program, as well as compare benchmarks from similar programs. The denominator reflects the ACM program's actual cost captured by the organization's accounting department, with capital investments in hardware and software prorated over a five-year period. If the KPI falls below one and/or other reasons for continuing it, an appraisal of the ACM program is called for at the earliest possible date to find out why. The range of ROI is typically greater than two in all mature programs. The ACM team leader collects program cost data and a member of the ACM team aggregates PDMR cost avoidance and cost savings data provided by maintenance crew leaders.

Formula

$$\textbf{ACM Program ROI} = \left(\frac{\textbf{Component 1}}{\textbf{Component 2}}\right)$$

Component Definitions

Component 1	Cumulative costs avoided due to ACMR or PDMR events for specific periods of time calculated in the KPI titled *Individual and Cumulative Cost Avoidance From ACM Program Finds*
Component 2	Cost of an ACM program for the same period of time as above, where cost of the ACM program equals the cost of capital investment prorated over five years (i.e., one fifth of initial capital investment per year) plus annual cost of ACM equipment repair, software upgrades, calibration, consumables, outside support, including certification and training for maintenance crews, modifications to equipment for safety of ACM data collection and cost of ACMMS

Qualifications

- Cost of labor for ACM team personnel should not be included if personnel were merely reassigned without relief or addition of personnel to the maintenance workforce.
- Cost of labor for maintenance crew ACM practitioners is not included since the tools used are essentially no different than others carried in their on-site tool kits. Time for using any individual tool also is not tabulated.
- Cost of ACM hardware purchased years before the start of a new or expanded in-house ACM program and retrieved for use by the ACM team should not be included in the program's cost.
- Cost of inexpensive, easy to learn and use ACM hardware for crews and all other ACM equipment and software purchased for ACM team and maintenance crew ACM practitioners at the time of being the in-house program should be included and prorated.

- Cost of the lubricant and wear particle analysis (L&WPA) program is not included if the decision was made to initially keep it separate. The L&WPA program would have its own set of KPIs. Later, if it is included as one of the condition monitoring functions of the ACM program, the cost of the programs would be combined and KPIs adjusted accordingly.
- The program cost for the 2014 recipient of the Uptime Awards' ACM Program of the Year was calculated using the formula for Component 2 shown in the component definition table for the period of September 1, 2012 (effective start date of the in-house ACM program) to August 31, 2013. The cost was $81,000. It is used in the following sample calculation:
- Costs avoided due to PDMRs reported in the *Finds-of-the-Week* newsletters. Twenty-five percent of total finds was $342,741.82 from September 1, 2012 to August 31, 2013. The total prorated (over five years) capital and annual cost of the ACM program for the same period was $81,000.

ACM program ROI = $342,741.82/$81,000 = 4.23

In order to obtain Component 1 in the ROI KPI, another KPI, *Individual and Cumulative Cost Avoidance From ACM Program Finds*, must be assiduously pursued. An explanation of this KPI follows.

KPI TITLE: INDIVIDUAL AND CUMULATIVE COST AVOIDANCE FROM ACM PROGRAM FINDS

Purpose and Benefit

The desired effects of a well-functioning ACM program are early detection of degrading conditions in assets monitored and timely, cost-effective restoration with no collateral damage and/or loss of production. When degradation is not detected and/or left unattended, complete failure can occur, resulting in a greatly increased cost of restoration, substantial downtime, loss of personnel productivity and lost production opportunities. In the case of wastewater treatment plants, for example, it also could result in failure to meet permit requirements, damage to the environment and penalties for noncompliance. One measure of the ACM program's worth is determined by calculating restoration cost avoidance for individual assets subject to monitoring, event by event, and adding these up for specific periods of time (e.g., year-to-date, full year and life of program).

Definition

This KPI is the summation of some portion or up to all cost avoidances on all assets subject to ACM for specific periods of time. There is no target value or range for this KPI. It should be tracked throughout each year and the total closed out at the end of each fiscal year for later calculation of return on investment for the program. The cumulative total is updated with each new event when PDMR WOs are completed in the CMMS. Accuracy is determined by the ability of maintenance crew leaders to estimate, based on historical data, if possible, the cost of restoration if the asset had been allowed to run to complete failure. This removes the ACM team from performing an assessment of its own success. The team merely aggregates the information provided by others.

Explanation and Usage

This KPI is used to determine the relative value of an ACM program as part of a proactive maintenance strategy as compared to a reactive maintenance strategy. It is used as a stand-alone KPI and in the calculation of return on investment of an ACM program (see next KPI). The KPI may be viewed in a spreadsheet maintained by the ACM team and used in various presentations throughout the year.

Formula

$$\sum_{\text{Event 1}}^{\text{Event N}} \textbf{Cost avoided due to PDMR 1} + \textbf{Cost avoided due to PDMR 2} + \textbf{Cost avoided due to PDMR “N”}$$

$$= \textbf{Cost avoidance for a specified period}$$

Component Definition

Cost Avoided = The estimated cost to restore an asset to full function had it run to complete failure *minus* actual cost of restoration entered into the CMMS after completion of a PDMR work order.

Qualifications

- Initially, cost avoidances may be calculated only for some portion of PDMRs, such as those reported as “finds-of-the-week.” These may represent between 10 percent and 25 percent of all PDMR WOs generated early in a new ACM/PdM program.
- Later, cost avoidances should be calculated for all PDMRs having some threshold value.

Sample Calculation

Estimated cost had asset run to failure = $49,000; Actual cost of PDMR (e.g., parts, consumable materials, contractor support, repair shop cost, etc.) = $9,555.

Cost avoidance for this PDMR = $49,000 - $9,555 = $39,445

The process for determining cost avoidance is shown in the process diagram in Figure 12 (see following page).

Note that the calculations are **not** performed by the ACM team, but by maintenance crew leaders. The ACM team merely totals all the cost avoidance amounts provided by all crew leaders and makes the accounting subject to audit by a third party, if considered necessary.

If the results are not there and the organization is not seeing measurable benefits, the ACM specified portion of the maintenance strategy may not actually be in place. Audit the maintenance program by comparing the in-place program to the recommended tasks derived from any source, such as an RCM or TPM initiative, or even from original equipment manufacturers, to see how well they match.

Corrective maintenance events also might be evaluated to determine if the failure mode(s) represented by each event should have been prevented by an ACM-based task. An appendix in Reference 1 listed in Section 7.1 provides a comprehensive multi-technology audit package that may be used. Reference 4 includes guidance for auditing the vibration analysis technology component of an ACM program.

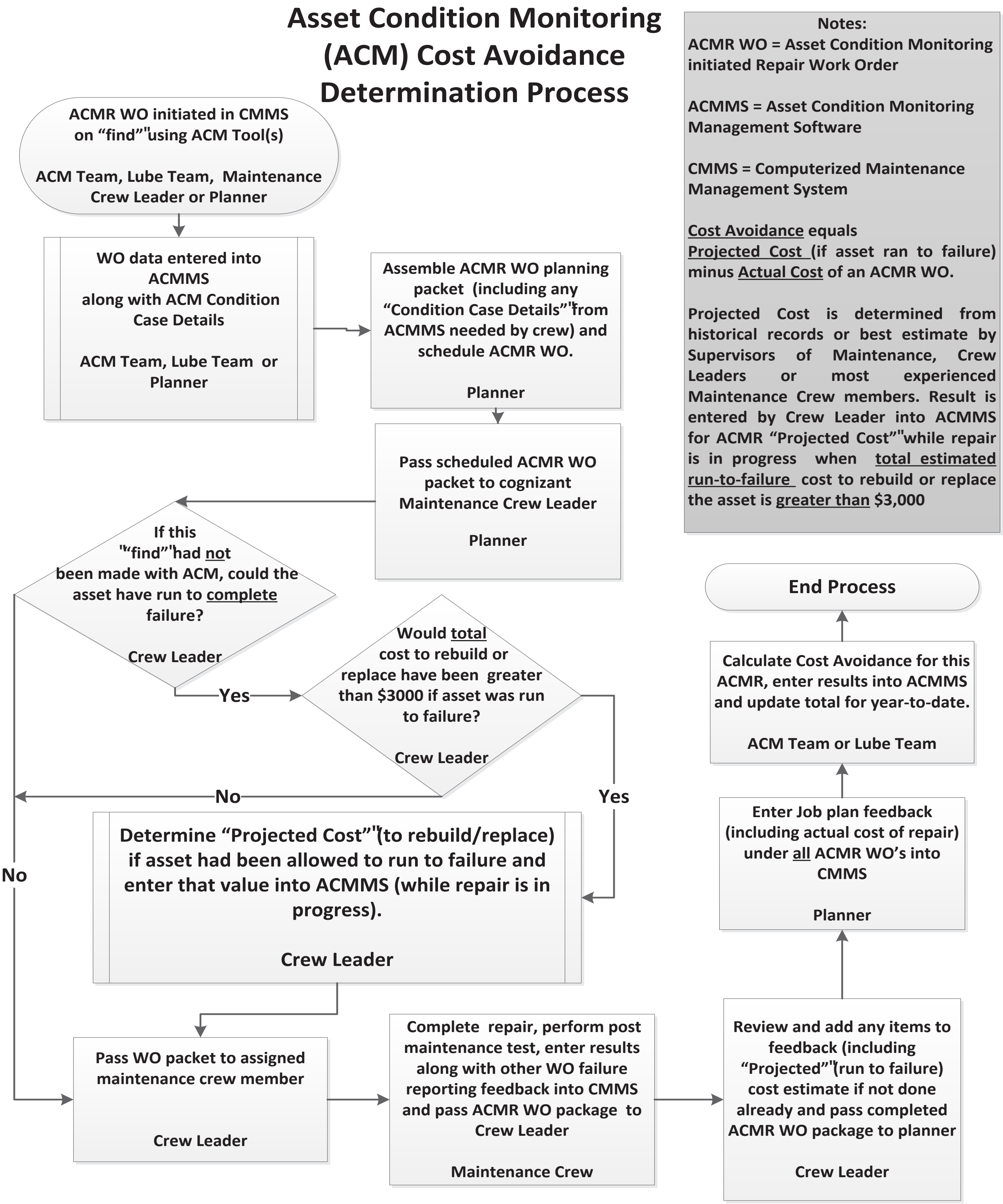


Figure 12: ACM cost avoidance determination process

6.0 SUSTAINING THE ACM COMPONENT OF A MAINTENANCE RELIABILITY STRATEGY

Sustaining the ACM component of an overall maintenance reliability strategy requires constant attention to prevent its demise. This fact is well known by ACM contractors who see their services terminated when a program is taken over by in-house staff and then are called upon in a few years to bid again on providing services. Some of the reasons for this type of chain of events are explained in this chapter.

6.1 Impact of Culture and Other Factors in Sustaining Any Initiative

With the achievement of a successful ACM initiative, the organization should be experiencing positive results and ready to sustain and increase the impact that ACM can provide. The following cultural and organizational factors will affect the long-term success of ACM, as well as many other worthwhile efforts.

1. Prior history of the organization in change management or bureaucratic elasticity. Will it work for awhile then return to what you did before?
2. Steadfastness of management and supervisor support for new initiatives. Is the organization saturated by the “flavors of the month” or initiative overload?
3. The likelihood the recommended maintenance tasks identified will be permanently adopted.
4. A commitment to cross-functional defect elimination (DE) teams.
5. A commitment to procedure-based maintenance. Without it, how are changes going to remain in existence?
6. A procedure-based maintenance environment that has a procedure compliant culture.
7. Maintenance requirements that are routinely performed on the basis of formal schedules.
8. The ability to set aside a recurring annual budget to continue ACM.
9. Willingness to support, with needed resources, changes to the ACM initiative when the need arises from the study of KPI analysis results.

The maintenance reliability community needs more and better reference material.

These factors illustrate that sustaining an ACM program is not easy. It is hard to find good technical and psychological studies on how to sustain **any** program. All organizations need to sustain processes and systems, but guidance that tells how to do it falls short. The maintenance reliability community needs more and better reference material. Please consider sharing your organization's successes and lessons learned in the ACM area, perhaps at a future conference by presenting a professional paper or writing an article for one of the publications mentioned in Section 2.1.

Sustaining performance in ACM is linked to the value of maintenance strategies developed, implementation of those strategies and continued improvement within the living program. There are enablers for achieving high performance in these areas and for sustaining it.

Some proven enablers for attaining and sustaining excellence in ACM are:

1. Set and follow a strategic vision or direction to guide improvement;
2. Involve senior managers visibly in key improvement and living program activities for their own understanding and to signal commitment;
3. Appoint and rely on a champion or change agent to own the effort;
4. Create a simple, formal process to document and review improvement ideas from the shop floor;
5. Encourage experimentation by involving as many affected operations and maintenance staff as possible and make decisions in teams about the way they work;
6. When making changes to maintenance strategies, formally introduce them through training for ALL involved;
7. Follow written standards for processes and procedures every day, during every shift and check to ensure it;
8. Monitor improvements made by ACM and formally communicate results;
9. Focus senior and middle managers and supervisors on supporting all these proven enablers through ownership by setting improvement targets and making people responsible for reaching those targets.

Highly successful organizations adopt a continuous improvement approach with these elements that can be described as a *living reliability program*. Note that continuous improvement is not the same as continuous change. If an organization is seeing results, it needs to be very careful about what it changes. The living reliability program establishes the resources, including budgets, and the roles, expectations and skill sets needed to gather additional feedback to continue improving the maintenance strategy (e.g., adjusting periodicity).

As shown in previous sections, an ACM initiative must support a maintenance strategy. The strategy is implemented into the EAM and/or CMMS and performed as part of the work execution processes. With a living program, failures are analyzed with tools, such as root cause analysis and defect elimination methodologies. Findings are then reviewed and acted upon in conjunction with the results from other initiatives, such as an RCM project. Maintenance strategies are either validated or modified with the new data and required approved changes implemented in a closed loop (i.e., continuous improvement) fashion back into the EAM/CMMS. When this becomes second nature, the reliability culture will be a way of everyday life.

6.2 The People Factor of an ACM Initiative

Sustaining an effective ACM program requires all key people involved to carry out their responsibilities regarding it to the best of their ability. Roles and responsibilities of key personnel associated with a typical ongoing ACM program are listed in this section.

ACM Program Executive Sponsorship

- Provide ongoing active support for the initiative
- Encourage subordinates to cooperate to make the initiative a continuing success

Maintenance Manager

- Keep upper level managers constantly advised of results from ACM efforts so they never lose confidence in the program and continue to place allocation of needed resources high on their list of priorities
- Direct and supervise all aspects of the overall ACM program
- Allocate and assign personnel, material and funding resources needed to carry out a vigorous ACM program

- Periodically review ACM key performance indicators to determine if program changes are needed to maintain or move KPIs in positive directions
- Facilitate and promote cooperative efforts between maintenance and other departments (e.g., engineering, information technology, procurement, operations, stores, etc.,) to further the goals and objectives of the ACM program
- Keep current on developments in the ACM field, such as the use of wireless technology, Internet of Things (IoT) or Industrial Internet of Things (IIoT), big data management and advanced analytics
- Encourage preparation of professional papers by personnel associated with the ACM program for conference presentations and trade magazine articles and ensure upper level management knows about them (See a partial list of conferences and publications in Section 2.1).

ACM Champion

- Facilitate and promote cooperative efforts of first-line maintenance leaders and personnel they supervise in pursuit of goals and objectives of the ACM program, including, but not limited to, training and orientation of ACM and lubrication (lube) practitioners
- Provide support for the ACM team leader and ACM and lube team members in pursuit of their training and certification in predictive technologies and related areas
- Scrutinize and prioritize requested budget line items of the ACM program, balance them with needs of other programs within the scope of your area of responsibility and defend, promote and obtain approval for those that are consistent with the overall goals of the organization
- Review ACM key performance indicators on a periodic basis and provide support for moving them in positive directions
- Support and defend capital improvement projects for improving safety and productivity with the application of ACM technologies

ACM Team Leader

- Provide day-to-day direction and supervision of members of the ACM team in carrying out the ACM portion of the overall asset management strategy of the organization
- Serve as a member of the lubrication charter team during its formative stages

- Facilitate cooperation and provide support, assume responsibility, or lead the lube team as needed to achieve the lubrication program's goals
- Perform the duties of administrator for the asset condition monitoring management software (ACMMS) program
- Coordinate entries between CMMS and ACMMS to ensure commonality and pursue arrangements for secure communications between the two
- Keep the ACM master plan current, initiating changes and revisions as needed and doing so at least annually
- Consolidate and submit annual ACM budget requests and supporting justification and oversee action items needed for approved budget expenditures
- Periodically provide ACM key performance indicator data for management review and appropriate follow-up actions, such as including them in required reports
- Continually assess the mix of predictive technologies and associated tools to determine any changes or additions needed to attain ACM program goals, giving consideration to advancements in the field
- Facilitate and pursue implementation of ACM related action items resulting from activities of the reliability program (e.g., RCM, a derivative or variant, risk threshold investigations, root cause analysis and defect elimination studies)
- Generate inputs for ACM team communications per guidelines in the ACM master plan
- Generate ACM case studies per the ACM master plan and maintain a case file for training and benchmarking purposes
- Serve as ACM task team participant on other ad hoc committees and in meetings affecting the ACM program
- Provide technical inputs for statements of work to RFP development teams for periodic competitive procurement solicitations for ACM support services contracts
- Oversee contractor efforts in support of the ACM program, including annual assessment of performance and initiation of annual extensions (or not) based on that assessment

- Coordinate training of ACM team members and ACM practitioners and orientation of maintenance first-line leaders, other supervisors or managers of maintenance, and others on progress and accomplishments in ACM technology application
- Coordinate and execute the schedule for periodic calibration of ACM instruments used by the ACM team and maintenance crew ACM practitioners
- Originate, in cooperation with reliability engineer(s), requests for capital improvement projects for installation of modifications needed to assure safety and productivity in applying ACM technologies and track and report progress (or lack thereof) in their implementation
- Participate in cooperation with reliability engineers in design reviews needed to ensure new plant systems have features specified to assure safe and productive ACM technology application
- Maintain a "museum" of ACM related annotated exhibits showing both successes, missed detections and other items useful in training, orientation and benchmarking visits

ACM Team Members

- Commit to becoming certified in technologies assigned by deadline dates set for each target level of certification or category after taking all required training courses and performing all on-the-job experience requirements
- Assure ACM tools used are maintained in secure and current calibration status at all times
- Establish mentor training to practitioners assigned to learn about and apply easy to learn and use ACM tools, such as vibration meters, infrared thermography and ultrasonic analysis instruments
- Provide orientation to coworkers, their supervisors and upper level management, as well as members of organizations, such as operations, engineering, etc., with which they interface, on the basics of the tools they use in carrying out the overall strategy of the organization
- Assist the ACM team leader and champion in populating KPIs with valid data as they become available

ACM Practitioners

- Accept assignment of one technology or more and commit to completing training on the use of the associated tool(s)

- Maintain the tool(s) assigned in a secure and up-to-date calibrated status at all times
- Cooperate closely with ACM team members as they carry out their responsibilities on assets for which they are assigned responsibility, including, but not limited to:
    - Assisting in baseline data collection and comparing results from practitioner tools to those from more sophisticated tools used by the ACM team members
    - Reporting results of post maintenance testing to the ACM team and arranging for the team to collect new baseline information under the optimum conditions (e.g., load, throughput, or other factors)
    - Conducting post maintenance testing to determine if repairs conducted have eliminated defects identified by ACM, allowing an asset to be turned over promptly to operations for use
    - Providing input for communications concerning ACM program accomplishments, case studies for use in orientation and training of organization personnel and visitors engaged in benchmarking or educational events

6.3 The Importance of Processes and Communications

All personnel involved in any way with asset condition monitoring need to know who to interact with and what is required of them to support the overall effort. In support of ACM, the more important processes are listed here, but all are depicted in Reference 1 of Section 7.1 and as indicated within this guide.

- ACM Data Collection Process
- ACM Post Maintenance Test Process
- ACM Baseline Data Collection Process
- ACM Cost Avoidance Calculation Process (see Figure 12)
- ACM Basic Process
- ACM Team Lines of Communication and Authorized Interactions (see Figure 13)

For the most productive approach, authorization for direct interaction across departmental and plant lines should be mandated by the executive sponsor, thus bypassing any organizational silos that often slow down, allow for misinterpretation and otherwise impede what should be a smoothly running organization and reliability strategy. Figure 13 illustrates the organizational relationships and lines of communication for an organization with many geographically distributed plants serviced by a single ACM team.

In Figure 13, the "Find-of-the-Week" editor is the person designated to write one page summaries of a selected ACM discovery or "find" and follow-up efforts to repair the asset. These documents are used to educate and inform all recipients from top management to maintenance crew personnel of the achievements under a condition-based reliability strategy. The corrective work

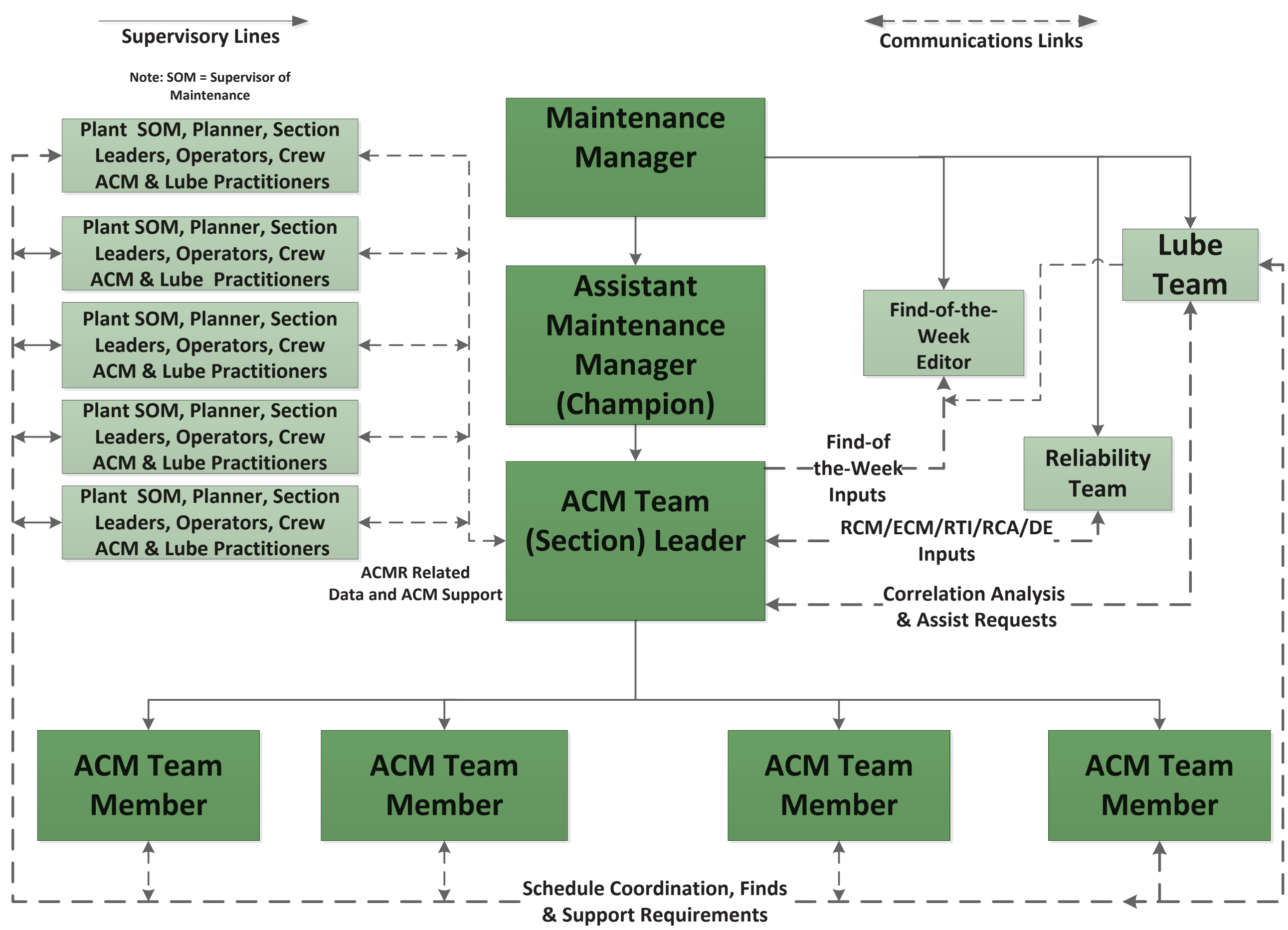


Figure 13: ACM team lines of communication and authorized interactions

order, details of the issue detected and follow-up after the work is completed help to validate the program and keep momentum moving forward. The content and other uses of these documents are described and illustrated in Reference 1 in Section 7.1. Also, see the glossary in Section 7.2 for descriptions of ECM, RTI, RCA and DE.

6.4 Summary

This Asset Condition Monitoring Project Manager's Guide presents many things that those in charge of maintenance reliability for an organization should take into account before committing to and starting an ACM initiative. There are many pitfalls to avoid in bringing the project to a successful conclusion. It must be appreciated that the whole effort may take a long time, up to several years in all, but the results of past successful projects have proven that it is worth it.

The information in this guide increases the chances for success of an ACM project by calling attention to causes of previous failures and providing the most meaningful basis for proving success – metrics selected during the decision and resource allocation phase and tracked and analyzed faithfully during all ensuing phases of a typical ACM project. Use the guide's comprehensive lists of readiness factors, pitfalls to avoid and risks that should be considered, mitigated and used to aid in deciding whether or not to proceed with an ACM project and how to proceed after the "go" order.

Once the decision is made to proceed and resources are allocated, utilize the guide's reports to evaluate project progress during implementation and metrics for both implementation and the final ongoing integrated and fully functional phase of an initiative. Many of the metrics are representative of those that have been used in the past on successful projects. Other metrics may be added or substituted, as long as the principles of comparison (e.g., not trying to compare large and small plants or include assets not subject to ACM in ACM-focused KPI calculations) are followed.

And always remember:

The asset condition monitoring initiative is a key component to your site's reliability culture.

7.0 REFERENCES AND GLOSSARY

7.1 References

The following list of publications elaborate on the material covered or mentioned in this guide. Each of them is a highly significant contribution to the industry and is worth the time to read and learn more about achieving success with ACM.

1. Nicholas, Jr., Jack R. *Asset Condition Monitoring Management*. Fort Myers: Reliabilityweb.com, 2016.
2. Fortin, John. *Why Execution Fails and What to Do About It*. Fort Myers: Reliabilityweb.com, 2016.
3. Zach, Tacoma. *Criticality Analysis Made Simple.* Fort Myers: Reliabilityweb.com, 2014.
4. Friedman, Alan. *Audit It. Improve It! Getting the Most From Your Vibration Program*. Fort Myers: Reliabilityweb.com, 2016.
5. Reliabilityweb.com. *Certified Reliability Leader Complete Body of Knowledge.* Fort Myers: Reliabilityweb.com, 2014.
6. Reliabilityweb.com. *Uptime Elements – A Reliability Framework for Asset Performance*. Fort Myers: Reliabilityweb.com.
7. Gulati, Ramesh; Kahn, Jerry; and Baldwin, Robert. *The Professional's Guide to Maintenance and Reliability Terminology*. Fort Myers: Reliabilityweb.com, 2010.
8. Reliabilityweb.com. *Reliability-Centered Maintenance Project Manager's Guide*. Fort Myers: Reliabilityweb.com, 2014.
9. Industry Experts. *The (New) Asset Management Handbook – A Guide to ISO55000*. Fort Myers: Reliabilityweb.com, 2014.
10. Nicholas Jr., Jack R. *Advancing Reliability and Maintenance*. Fort Myers: Reliabilityweb.com, 2008.
11. Nicholas Jr., Jack R. *Advancing Reliability & Maintenance to Meet and Beat Global Competition (DVD).* Fort Myers: Reliabilityweb.com, 2011.
12. Mitchell, John S. *Physical Asset Management Handbook 4th Edition.* Fort Myers: Reliabilityweb.com, 2012.

13. Plucknette, Doug and Colson, Chris. *Clean, Green and Reliable: A Sustainable Reliability Guide For Industrial Plants.* Fort Myers: Reliabilityweb.com, 2012.

14. Ledet, Winston P.; Ledet, Winston J.; and Abshire, Sherri M. *Don't Just Fix It, Improve It! A Journey to the Precision Domain*. Fort Myers: Reliabilityweb.com, 2009.

15. Ledet, Winston P.; Henley-Ledet, Michelle; and Abshire, Sherri M. *Level 5 Leadership at Work: Understanding Leadership as a Group Process, Not a Lone Hero Journey*. Fort Myers: Reliabilityweb.com, 2012.

16. Williams, Cliff. *People – A Reliability Success Story*. Fort Myers: Reliabilityweb.com, 2012.

7.2 Glossary of Terms, Abbreviations and Definitions

Experience in many organizations has shown that adopting a consistent use of terminology is a leading enabler of success. The terms, abbreviations and definitions included in this glossary are a brief, to the point reference designed to help explain those maintenance reliability terms that relate to an ACM project or program. It is not intended to be a conclusive list or fully capture the nuances of any particular term.

80/20 Rule – Known as the Pareto principle, most defects come from relatively few causes, that is, 80% of the defects come from 20% of the possible causes.

Asset – A thing, entity, or item that has actual or potential value to an organization.

Asset Condition Monitoring (ACM) – See Condition Monitoring.

Asset Condition Monitoring Training and Certification Organization (ACMTCO) – A commercial organization that conducts classroom courses, and practical and certification examinations on specific condition monitoring technologies, such as vibration analysis, infrared thermography, ultrasonic analysis, on-line and off-line motor circuit testing, lubricant and wear particle analysis, and visual testing/inspection.

Asset Lifecycle – Stages or phases involved in the management of an asset during its life. These phases include concept, design and development, build, install and commission, operations, maintenance, decommissioning and disposal.

Asset Management – An organizational process to maximize value from an asset during its life; The management of the life of an asset to achieve the lowest lifecycle cost with the maximum availability, performance efficiency and highest quality.

Availability –

> **OEE Basis** – The percentage of time an asset is operating satisfactorily (uptime) compared to when it is scheduled to operate; Synonymous with operational availability; Expressed as a formula using mean time between failures (MTBF) and mean time to repair (MTRR):
>
> A_1 = MTBF/(MTBF + MTTR);
>
> **Reliability Basis** – The probability that an asset is capable of performing its intended function satisfactorily, when needed, in a stated environment or stated conditions; Availability is a function of reliability and maintainability.

Bad Actor – A system where 80 percent of the problems (e.g., failures, costs, etc.) to the organization or site can be attributed to 20 percent of the systems; See 80/20 Rule.

Baseline Testing – Collection of performance and condition data from new assets and after major modification or repair under optimum operating circumstances to use as a basis or starting point for analysis in subsequent operating cycles.

Best Practice – A technique, method, or process that is more effective at delivering a desired outcome than any other technique, method, or process. This practice usually becomes a benchmark; a practice that leads to superior performance in a specific process.

Bureaucratic Elasticity – The characteristic of an organization that begins a new initiative and then, because of departure, shift of attention, or lack of firm leadership by the initiating manager or supervisor, returns to the traditional way of doing whatever the new initiative was supposed to change.

Business Case – A report and/or presentation that captures the reasoning for whether or not a project or task should be initiated.

Business Case Preparation Phase – The first phase of an ACM program initiative where the evidence is gathered and organized to aid in a decision of whether or not to proceed to initiate or change all or part of an asset condition monitoring program.

Champion – One who facilitates a paradigm change in the understanding and practice of a specific discipline or cause; A senior manager or leader who supports and addresses organizational issues. Within the maintenance reliability field, champions may be assigned or self-appointed to an ACM or reliability-centered maintenance (RCM) project, support a condition monitoring/predictive maintenance team, or a total productive maintenance or procedure-based maintenance initiative; Typically, the champion title does not appear on an organizational chart, although the official title of a supervisor, manager, or key specialist may imply the incumbent is the logical choice.

Condition-Based Maintenance (CBM) or On-Condition Maintenance – Maintenance based on the actual condition (health) of an asset as determined from noninvasive measurements and tests. CBM allows preventive and corrective actions to be optimized by avoiding traditional calendar or run time directed maintenance tasks.

Condition Monitoring (CM) – Continuous or periodic measurement and interpretation of data to indicate the condition of an asset to determine the need for maintenance; Synonymous with asset condition monitoring (ACM); Older terms include predictive maintenance (PdM) and nondestructive testing (NDT), each of which has different definitions in this glossary.

Corrective Maintenance (CM) –

(1) Repair actions initiated as a result of observed or measured conditions of an asset after or before the functional failure;

(2) When repair actions resulting from preventive or predictive analysis can be distinguished from unexpected failures in the computerized maintenance management system (CMMS), CM work orders are categorized separately from work orders resulting from preventive maintenance initiated repairs (PMR) or condition monitoring initiated repairs (PDMR). This allows a determination of how “proactive” a maintenance program is and how effective either a PM or PdM element of an overall maintenance strategy is working. The formula for the amount of maintenance work that is proactive is: (# of PMRs + # of PDMRs) divided by (# of CMs + # of PMRs + # of PDMRs) expressed as a percentage.

Critical Asset – An asset with the potential to significantly impact the achievement of the organization’s objectives; Assets that have been evaluated and classified as critical due to their potential impact on safety, the environment, production and operations if they fail and lead to the shutdown of the operation.

Decision and Resource Allocation Phase – The period of an ACM initiative in which a determination is made using a business case, which may include a selection of metrics, measures, or key performance indicators (KPIs), as to whether or not an ACM initiative, such as new start-up, restructuring, or expansion will meet an organization's investment criteria and improvement in safety, risk mitigation and/or economic performance; Improvement is created through execution of a maintenance program based on ACM principles, among other elements of an overall maintenance reliability strategy.

Defect – A condition that causes deviation from design or expected performance and leads to failure; A fault.

Defect Elimination (DE or De) – The identification of a defect (or nonconformance) and its removal. A methodology conducted by a multidisciplinary team of subject matter experts to eliminate *known,* relatively easily correctable defects caused by aging, wear and tear, careless work habits, or inadequate replacement parts; DE analysis meetings typically are completed in a day because they deal with approved, authorization for change action(s).

Design Defect – A failure that was caused by improper (bad) design; Occurs during the design, fabrication, acquisition and installation phases of an asset's lifecycle.

Design Modification – An alteration to the configuration of an asset or its process that improves its reliability, safety margin, maintainability, or operational performance, or makes a formally hidden failure evident to operators and maintainers in the course of their normal duties.

Detection (Sensitivity) – A ranking scale that defines the likelihood of detecting a failure or effect of the failure.

Downtime – The amount of time when the assets/machines in a plant or facility are not producing because of failure, down for maintenance, or other reasons; The sum of scheduled and unscheduled downtime.

Effects – The consequences of failures.

Effects Analysis – The study of consequences or effects of failures.

Enterprise Asset Management (EAM) or Enterprise Resource Planning (ERP) – An information system that integrates all asset related applications for an entire enterprise; Comprised of a single or integrated suite of applications to manage a variety of functional areas, including maintenance, materials management, production, sales and marketing, distribution, finance, field services and human resources; Provides information linkages to help companies monitor and control activities in geographically dispersed operations.

Equipment Uptime – The time period during which an equipment item is performing its function(s) and/or providing a service; The actual running time.

Experienced Centered Maintenance – An RCM variant methodology applied by a multidisciplinary team of subject matter experts on better to well-behaved systems (i.e., 20/80 systems – the 80 percent of systems where only about 20 percent of all problems develop) in order to answer these questions:

A. Are current preventive maintenance (PM) tasks, if any, performed on the system really worth it in terms of applicability (i.e., they work and actually do or can find failure modes) and is each cost-effective?

B. Could any of the corrective maintenance events on the system in the past five years been avoided if a proper PM task was in place?

C. Can the team hypothesize any failure modes not already covered in the previous two questions that could potentially produce severe consequences, such as affecting safety or having outages requiring substantial downtime and/or outage for maintenance?

Facilitator – An individual, often a recognized expert from outside an organization, responsible for creating a favorable environment that will enable a team or group to reach consensus or achieve its goal by bringing together the necessary tools, information and resources to get a job done or achieve a specific goal.

Failure – The inability of an asset to perform its designed function.

Failure Finding (FF) Tasks – A scheduled task that seeks to determine if a hidden failure has occurred or is about to occur.

Failure Mode – The way or manner in which an asset might fail.

Failure Mode Analysis – A technique to examine an asset, process, or design to determine potential ways it can fail and its potential effects on required functions, and to identify appropriate mitigation tasks for highest priority risks.

Failure Mode and Effects Analysis (FMEA) – A procedure in which each potential failure mode in every subitem of an item is analyzed to determine the effect on other subitems and on the required function(s) of the item/asset.

Failure Rate – The number of failures an asset suffers over a period of time; For the majority of assets, failure rate is considered constant over the majority of useful life of an asset; It is normally expressed as the number of failures per unit time; Denoted by lambda (λ), failure rate is the inverse of mean time between failures.

Find – An abnormal condition detected in an asset using human senses and/or the aid of ACM technology, tools, or techniques.

Forced Outage – A shutdown for corrective maintenance when an asset experiences an unexpected failure that prevents its function.

Function – An action performed by a component, device, asset, department, or person that produces a result.

Functional Failure – A state in which an asset or system is unable to perform a specific function to a level of performance that is acceptable to its user.

Hidden Failure – A failure mode that is not evident to an individual or operating crew under normal circumstances.

Implementation and Short-Term Benefits Phase –The fourth phase of a five-phase ACM project or initiative that ends with the completion of the last recommended implementation action item; Implementation overlaps with the development and procurement phase of an ACM initiative; Implementation involves management of change to a new or revised strategy and its execution; The most successful implementations use an organized approach, such as the Shewhart plan-do-check-act (PDCA) methodology articulated in Six Sigma (www.isixsigma.com) and other problem-solving processes.

Implemented Task or Decision – A project action item formally executed for the first time as part of a maintenance program strategy; For tasks, it is incorporated into an approved step-by-step procedure, with or without other tasks, formally scheduled and carried out at least once by personnel who have been oriented or trained, as needed, to carry it out; For RCM-based decisions, such as run to failure items that previously required a task that was not applicable and/or effective and other old program tasks for which there is no justification, all steps are taken to exclude them from the new program.

Installed Instrumentation and Parameter Analysis – Utilizing installed equipment instrumentation or selected additional non-intrusive sensors, some combination of critical parameters are chosen to indicate current condition or performance of operating equipment; Algorithms are developed to assist in analysis and alert and alarm levels are established to highlight developing situations which, if left unattended, may lead to complete loss of function.

Integrated and Fully Effective Phase – The fifth and final phase of an ACM program start-up, restructuring, or expansion; The process of sustaining full effectiveness is never-ending and repetitive due to changes in personnel, their training and certification levels, and other factors that demand constant management and supervisory attention.

Key Performance Indicator (KPI) – Provides current status and trend information regarding effectiveness of work processes; See Performance Indicators.

KPI Management Tool – A software program that collects KPI component data from CMMS, EAM, or ERP systems and calculates KPIs continuously or on demand.

Lubrication Task – A time- or condition-based action involving the addition or exchange of lubricant, such as grease or oil.

Maintainability – The ease and speed in which a maintenance activity is carried out on an asset; A function of equipment design usually measured by mean time to repair (MTTR).

Maintenance Backlog – Maintenance tasks that are essential to repair or prevent asset failures that are not yet completed.

Maintenance Program – A comprehensive set of maintenance activities, their intervals and required activities, along with accurate documentation of these activities.

Maintenance Strategies or Maintenance Reliability Strategies – A long-term plan covering all aspects of maintenance management that sets the direction on how assets will be maintained and contains action plans for achieving a desired future state; Four main types are run to failure, preventive, predictive and condition-based.

Maintenance Task Optimization – A methodology for adjusting an existing maintenance program to combine common tasks into more productive packages while eliminating overlaps, redundancies and ineffective or nonproductive efforts.

Mean Time Between Failures (MTBF) – A basic measure of asset reliability calculated by dividing total operating time of the asset by the number of failures over a period of time. MTBF is the inverse of failure rate (λ) and is generally used for repairable systems.

Mean Time to Repair (MTTR) – The average time needed to restore an asset to its full operational capabilities after a failure; A measure of asset maintainability.

Nondestructive Tests and Inspections – A technique intended to predict wear rate, state of deterioration, etc., without damaging or destroying the material or product being tested; Includes liquid penetrant inspections, magnetic particle inspections, radiography, active ultrasonics, visual tests or inspections and dimensional measurements.

On-Condition or Condition-Directed (CD) Tasks – See Condition Monitoring.

Operating Context – The environment in which an asset is expected to operate or be used; Describes current condition, environment and culture in which a piece of equipment operates, including, but not be limited to:

- Temperature (e.g., hot, cold, or severe swings);
- Dirty or dusty atmosphere;
- Wet or dry area;
- Corrosive, erosive, or abrasive environment;
- Dark or dimly lit;
- Noisy;
- Culture (e.g., goals and expectations not clearly defined, high level of emergency/demand work);
- Operating outside design expectations or performance standards;
- Asset condition (e.g., loose, improperly supported, improperly installed, improper design, damaged);

- Improper operation (e.g., start-up, shutdown, product change, setting, speed, flow, pressure);
- Human error (e.g., forgot to do, no checklists or procedures).

Operating Procedure – Detailed, step-by-step written procedure(s) and/or checklist(s) used to start, run, or stop an asset in the safest, most economical, productive and effective way; Changes initiated through RCM analysis are usually intended to eliminate or mitigate failure modes resulting from human error, or alter the way equipment is operated in order to protect it from functional failure; This may be done to protect the environment and/or the people who might be affected by a failure or the quality of the product or service provided by it; Failure finding tasks are often incorporated into operating procedures as the most logical and convenient way of performing them.

Operating Speed Rate – Used in OEE calculation, it is the total number of units of product or service produced multiplied by the theoretical cycle time and divided by actual cycle time; Expressed as a decimal number equal to 1.00 or usually less, or expressed as a percentage; See Speed Rate.

Operational Excellence – The point when each and every employee can see the flow of value to the customer and fix that flow before it breaks down or reduces the value delivery; Communicated in specific terms that are understood by all employees.

Operational Performance Testing – A broad category of operational tests to measure capacity, efficiency, integrity, quality of outputs, or some combination of critical parameters that best depict the condition of the equipment relative to plant or facility mission.

Operations Personnel – Employees working in the operations department.

Overall Equipment Effectiveness (OEE) – A measure of equipment or process effectiveness based on actual availability, performance and quality of product or output; Calculated by Availability % x Speed or Rate % x Quality %.

Performance Indicators – Measures to determine the performance of a function within a group, department, and/or organization; Synonymous with performance indices.

Performance Testing – A periodic check of a component's ability to perform its operational function; Usually applied to standby equipment or equipment operated only on demand;

Operating data collected during tests are analyzed to identify failure potential, as well as equipment capability to perform at a designated level of quality, output and efficiency; In a more general sense, can also include a variety of nondestructive tests, as well as visual inspections that can be done to check the physical integrity of components and examine for wear or defects.

Pilot Project – An initial effort undertaken to test the feasibility of applying results on a broader scale to determine whether such an initiative can be successful given the culture, resources required and benefits expected of it when applied throughout all applicable assets.

Planned and Scheduled – Activities in maintenance where resources are determined in advance and time is estimated to carry out the work.

Planned Maintenance – Tasks carried out on a regular, scheduled basis; Tasks may be predictive in nature (e.g., condition monitoring activities) or preventive (e.g., cleaning/changing filters, checking/adjusting clearances, etc.) to prevent an asset from deteriorating or breaking down.

PM and PdM Compliance – Expressed as a percentage, it is preventive maintenance (PM) or predictive maintenance (PdM) asset condition monitoring (ACM) tasks accomplished, divided by PM or PdM (ACM) tasks scheduled or required and multiplied by 100.

Post Repair Testing and Follow-Up – An excellent vehicle for maintenance follow-up; Post repair testing may be used to:

- Confirm the quality of the repair;
- Establish a new baseline for future predictions;
- Justify lifting previously imposed operating limits;
- Establish new limits if full capability is not restored;
- Verify or disprove the root cause ascribed to the failure;
- Document links between predictive indications and root cause for future analysts' use.

Predictive Condition Monitoring Analysis Method – A method of analysis that, when applied to data from a predictive technology, results in information of significance for evaluating current and forecasting future condition of systems or equipment; Examples include trend analysis, pattern recognition, correlation, tests against limits or ranges, relative comparisons of data and statistical process analysis.

Predictive Condition Monitoring Technique – The process or practice of applying the tool(s) for data collection, analysis and related factors that yield reliably actionable results.

Predictive Condition Monitoring Technology – A scientifically based means of sensing system or equipment condition and characteristics; Data obtained must be repeatable, used for analysis of current performance and/or condition and applied as a basis for predicting future performance and/or condition of the system or equipment.

Predictive Condition Monitoring Tool – Hardware and/or software used to collect, analyze and report on the condition or performance of an asset; Tools may vary depending on vendor sources and advancements in communications, computer science, special requirements (e.g., intrinsically safe for hazardous situations) and other factors that must be taken into account when conducting monitoring activities.

Predictive Maintenance (PdM) – See Condition Monitoring.

Preventive Maintenance (PM) – A maintenance strategy based on inspection, component replacement and overhauling at a fixed interval, regardless of its condition at the time; Usually, scheduled inspections are performed to assess the condition of an asset; PM examples: scheduled restoration tasks and replacement tasks.

Proactive Maintenance – The sum of all maintenance work completed to avoid failures or identify defects that could lead to failures (i.e., failure finding); Includes routine, preventive and predictive maintenance activities and work tasks identified from them; Used to determine percentages of proactive and reactive maintenance; See Corrective Maintenance, #2 definition.

Quality Rate – The number of good units divided by the total number of units produced; A factor expressed as a fraction or a decimal number equal to or usually less than 1.00, or as a percentage; Included in the calculation of OEE and total effective equipment performance.

RCM Derivative – An analysis methodology that produces a non-redundant, reliability-centered maintenance (RCM) like set of tasks; Time directed intrusive, time directed non-intrusive, condition directed and failure finding derive from what is already in the PM and/or PdM program or within the capability of PdM technologies used; See Reliability-Centered Maintenance (RCM) and Reference 12 in Section 7.1.

RCM Variant – A reliability-centered maintenance (RCM) methodology that skips or combines steps found in classical RCM or incorporates substitutes or supplements to FMEA in order to reduce the time and resources needed for a project; See Reliability-Centered Maintenance (RCM) and Reference 12 in Section 7.1.

Reactive Maintenance (RM) – Maintenance repair work done as an immediate response to an asset failure, normally without planning and scheduling; Synonymous with breakdown and emergency maintenance.

Reactive Work – Maintenance activities that occur with little or no notice; Activities that interrupt the weekly maintenance schedule and cost two to four times as much as when they can be planned and scheduled.

Reduced Speed – Losses incurred when equipment or assets are allowed to perform at less than design speed or capacity; Synonymous with capacity losses.

Reliability – The probability that a system will perform satisfactorily for a given period of time under stated conditions.

Reliability-Centered Maintenance (RCM) – A systematic, disciplined process for establishing the appropriate maintenance plan (requirements) for an asset/system to minimize the probability of failures; A process to ensure safety and mission compliance; Classical RCM is defined by SAE International's standards JA1011 and JA1012 and the seminal Department of Defense report titled, "Reliability-Centered Maintenance" and prepared under contract by United Airlines by coauthors F. Stanley Nowlan and Howard F. Heap; See RCM Derivative and RCM Variant.

Risk Threshold Investigation (RTI) – A short (-1 day) study by a multidisciplinary team of subject matter experts on relatively well-behaved systems that may never be subjected to any form (e.g., classical, variant, or derivative) of RCM analysis to ensure potential equipment problems/failures that individually could be quite serious or provide unnecessary risk are not present; The methodology was developed because the criticality approach used to define the importance of certain environmental, safety and operational goals was found wanting in several aspects; For example: a component could collect enough points from its 23 criticality criteria questions to be considered critical by its definitions, but would not necessarily be a risk because the consequences of its failure to the plant are relatively benign; A focus on identifying problems that could be really showstoppers and trying to avoid them; See Reference 1 in Section 7.1.

Root Cause – Failure or fault from which a chain of effects or failures originates.

Root Cause Analysis (RCA) or Root Cause Failure Analysis (RCFA) – Identification and evaluation of the reason for an undesirable condition or nonconformance; A methodology that leads to the discovery of the cause of a problem or root cause. Used to determine the underlying cause or causes of failure so steps can be taken to manage those causes and avoid future consequences of failure; Eliminating or mitigating root causes has the biggest impact on solving the problem.

Route List(s) and Schedule(s) – A compilation of asset condition monitoring data collection points and task periodicity (i.e., intervals) for collection organized by predictive condition monitoring technology entered into a CMMS, ERP and/or ACMMS; Used by ACM team technicians for scheduling data collection and analysis activities, determining compliance KPIs and, where available, assets at risk because of being overdue for monitoring or with an outstanding work order identifying a defect.

Run to Failure (RTF) – A maintenance strategy or policy for assets where the cost and impact of failure is less than the cost of preventive actions; A deliberate decision based on economical effectiveness.

Scrap Rate – The amount (e.g., tons, widgets, etc.) of irreversibly damaged product divided by the amount of total product in the same units produced by an asset; Damaged product must be scrapped, meaning recycled or disposed of and generally can't be sold at a price that recovers its total cost of production; Usually expressed as a percentage of throughput or output.

Showstopper – A problem so bad that is attracts the attention of senior management, regulatory authorities and personnel who must interrupt their normal activities to correct the problem so operations (i.e., the show) can be resumed.

Speed Rate – The ratio of theoretical cycle time divided by actual cycle time, where theoretical cycle time equals ideal speed (i.e., equipment capacity as designed or highest accredited speed, if higher) and actual cycle time equals run time divided by actual amount produced; Yields a decimal number equal to or usually less than 1.00, as expressed as a percentage; Used in calculation of total effective equipment performance (TEEP).

Subject Matter Expert (SME) – An individual, in-house or from an outside source, such as an original equipment manufacturer, widely recognized for knowledge and expertise in maintenance and/or operations of an asset; A maintenance or operations retiree whose expertise was not fully captured prior to retirement and is hired as a consultant for a limited period, such as for the analysis and/or implementation phase of an RCM project.

Task(s) – Specified maintenance action(s) taken to mitigate, prevent, or identify the onset or presence of an actual functional failure in an asset.

Task Periodicity – Frequency with which a specified maintenance action is taken on the same asset.

Throughput – The rate at which work proceeds through a machine or manufacturing process. May be expressed in tons or barrels, gallons per day, week, month, or year, widgets per hour, megawatt hours, etc.; Synonymous with output.

Time Directed (TD) Tasks – Tasks directly aimed at failure prevention and performed based on time, whether calendar time or run time.

Time Directed Intrusive (TDI) Tasks – A type of time directed task that defines actions requiring asset or process interruption where human error or just executing the task may cause a functional failure upon resuming operations after inspections, adjustments and lubrication tasks requiring shutdown/restart, tagout, opening, or disassembly; An intrusion that implies the introduction of induced risk of functional failure caused by the maintenance action itself; A goal of an RCM project should be to minimize time directed intrusive maintenance tasks.

Time Directed Non-Intrusive (TDN) Tasks – A type of time directed task that defines actions that do not require process or asset interruption, equipment shutdown, tagout, entry, or disassembly, thus minimizing the possibility of human error that could cause a functional failure.

Total Cost of Replacement Parts – Money spent annually to replace failed, worn, or scheduled replacement components on a given asset or an entire facility; A subset of total cost to perform maintenance.

Total Cost to Perform Maintenance – Total cost of labor, material, including cost of replacement parts, and overhead charged to a specific asset or an entire facility over a set period of time; Encompasses all maintenance support personnel costs, including indirect labor, contracted and outsourced maintenance and related expenses, such as transportation, packaging, storage and handling, training and annual capital investment in tools, instrumentation and materials used to maintain an asset, as well as allocated cost of utilities, insurance, taxes and factory supplies and consumables used by maintenance personnel in their daily work.

Total Effective Equipment Performance (TEEP) – A measure of overall asset or process effectiveness; Objective is to measure how well an organization creates lasting value from its assets; TEEP = utilization x availability x performance x quality = utilization x OEE.

Total RCM Program Decisions – The sum of all time directed intrusive (TDI), time directed non-intrusive (TDN), condition-directed (CD) and failure finding (FF) tasks and run to failure (RTF) decisions.

Unscheduled Downtime – The amount of time an asset is not capable of running due to unscheduled repairs, such as repair work not on the finalized periodic schedule (e.g., weekly, monthly, or annual), plus the amount of time beyond that formally allocated for scheduled downtime or scheduled outage.

Visual Inspection (VI) – Regular walk-around inspections of critical plant equipment and systems that can be invaluable to a condition monitoring program; Also called visual testing per ASNT's SNT-TC-1A standard.

ROOT CAUSE ELIMINATION IS KEY TO PRECISION LUBRICATION

By Jason Kopschinsky

According to industry estimates, most production organizations lose between 10 and 15 percent of their plants' total maintenance budgets each year due to downstream effects of poor lubrication. Poor lubrication, defined as too much or too little grease, lack of contamination control, using the wrong oil or grease, ineffective storage and handling, etc., is largely controllable and avoidable. To begin to curb these losses and redirect valueless tasks, one first needs to understand how machines fail.

Professor Ernest Rabinowicz spent much of his time at MIT researching machine wear and what he referred to as loss of usefulness. Rabinowicz found that as much as 70 percent of loss of machine life is due to loss of surface material or, in other words, wear. Machine wear can be further divided between corrosive wear and, to a much larger extent, mechanical wear.

The National Research Council of Canada furthered the understanding of the cause of mechanical wear by concluding that although several wear mechanisms exist, 82 percent of mechanical wear is caused by particle contamination. Wear from abrasion, erosion and fatigue make up the bulk of mechanical wear and all are a result of solid particle contamination. It stands to reason that if particles are the root cause of most of the wear occurring in machines, organizations should work to control particle ingression and have a method for removal when necessary. However, the key is to target the solid particles causing the most damage.

Unknown to many, the clearance sized solid particles are the most damaging. Although mechanical clearances in industrial machinery have a broad range, in most cases, particles are in the two to five micron range. Although you want to keep all particles out of your machinery and lubricant, it's the ones that fit between mating surfaces that create wear. Particles much larger than the clearance don't fit into the space and, conversely, particles much smaller can easily make their way through the clearance in the fluid film.

Although a robust predictive maintenance (PdM) program includes condition feedback technologies, such as oil analysis, vibration analysis, ultrasonic testing and infrared thermography, these tools provide data on a failure that has already begun. Rather, a precision lubrication strategy requires root cause elimination. A focus on contaminant control and elimination will prove to aid in component life extension and enhanced reliability.

ABOUT THE AUTHOR

Jason Kopschinsky is the Director of Reliability Services for Des-Case. Prior to joining Des-Case, Jason spent over a decade coaching clients in asset reliability and lubrication management. Jason has published a variety of technical articles on condition monitoring, contamination control, lubrication management and program management and has been invited to speak at numerous international symposia. Prior to joining Des-Case, Jason worked as Director, Technical Services at Noria Corporation, and as Director of Reliability Services at Trico Corp. Jason is a certified project management professional and a certified maintenance and reliability professional (CMRP) from the Society for Maintenance and Reliability Professionals (SMRP).

Jason's Core Expertise:

- Lubrication Improvement Project Management
- Lube Room Design and Storage & Handling Strategy
- Oil Sampling and Analysis Program Development
- Contamination Control Strategy
- Practical Case Study Analysis

WHAT ALIGNMENT MEANS TO AN ACM PROGRAM

By Florian Buder

Rotating machinery is susceptible to misalignment. Machines that are well aligned at the commissioning stage (i.e., asset condition monitoring analysis) and regularly maintained thereafter will quickly reduce both plant operating and maintenance costs. Intelligent and precise measurement and testing systems offer effective technological solutions in machine alignment and condition monitoring.

Laser precision alignment extends machine availability as the mean time between failures (MTBF) increases. It protects assets and increases product quality, as vibration is reduced to very low levels. When misaligned, the loading of the shafts increases significantly due to the reaction forces created within the coupling, hence reducing efficiency and increasing energy costs.

Unscheduled downtime puts a dent in your productivity, operating results and costs, therefore, it is important to rely on condition-based maintenance to keep your system producing. Condition monitoring means that every machine is regularly subjected to a health check. In the simplest case, the measurement instrument used to perform this check provides a numerical value that can be compared to a standard value to indicate the machine´s state, such as, good, okay, or bad.

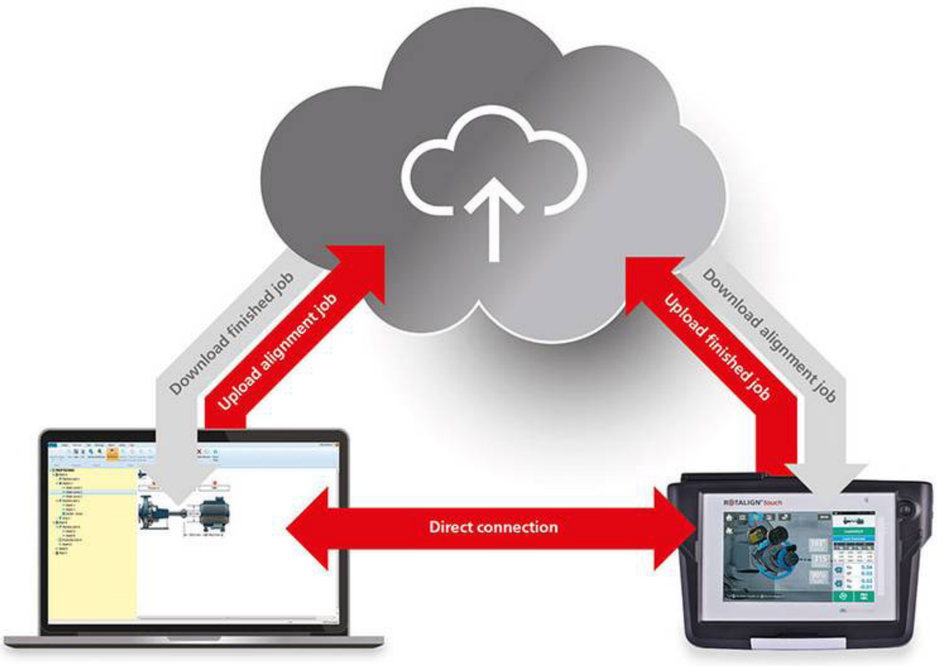
Optimal production and smooth processes are only possible when machines run without vibration. Identifying problematic machine conditions and, more importantly, eliminating their causes can be done through vibration analysis and monitoring systems.

These types of measurement systems can be used in many different alignment and vibration applications of rotating machinery. In addition to shaft alignment technologies, various geometric solutions can be utilized, including measurement of straightness and surface flatness, alignment of bores and turbine diaphragms, roll parallelism and live monitoring of positional change in machinery.

The Future of Alignment

The vast potential of Cloud-based technology is shaping the future of alignment. Cloud-enabled shaft alignment systems with integrated mobile connectivity allow full integration into the asset management and condition-based maintenance programs.

An important prerequisite for automation and plant management is communication among the machines. For this reason, connecting all the components within a plant is a central prerequisite for setting up the so-called smart factory. The vision of the smart factory also requires all upstream and downstream production processes to be interconnected. Such a plant monitoring system also



requires interfaces for the seamless data exchange between plant control, process visualization and the operator.

Maintenance reliability managers will be able to remotely prepare alignment jobs in the alignment software and connect to the Cloud to transfer them to a device anywhere in the world. Alignment technicians can receive alignment jobs directly on their touch screen mobile device. Once completed, the jobs can be uploaded wirelessly back to the Cloud.

Comprehensive device connectivity or a Cloud solution also will be a key requirement when implementing maintenance solutions.

ABOUT THE AUTHOR

Florian Buder is CEO for the North American PRUFTECHNIK operations. He joined PRUFTECHNIK AG in Germany in 2005 as a service and application engineer. The reliability-centered maintenance specialist also served as condition monitoring division manager for PRUFTECHNIK's operation in Montreal, Canada, and managing director of the company's Canadian operation. He holds a Mechanical Engineering degree from the University of Munich, Germany, and an MBA from John Molson School of Business - Concordia University, Montreal. He has 12 years of experience in the industrial maintenance and reliability world.

HEAR SDT MORE

ULTRASOUND “FITS” ACM

By Allan Rienstra

Asset condition monitoring (ACM) groups together complementary technologies, each designed to shed insight about machine health. The thought process is to share multiple sources of information, enabling reliability teams to arrive at the best actionable maintenance decision.

Quite simply, ACM assures you that everything is going to be okay and, if not, helps you decide what to do about it.

Ultrasound is revered by many as the cornerstone technology inside the asset condition management domain. Ultrasound testing (Ut) identifies many common machine defects.

Frequently used for leak detection and bearing monitoring and lubrication, the technology is also used for steam trap monitoring, electrical inspections, tightness testing, rotating machinery condition, and valve and hydraulic testing. These eight application pillars of ultrasound make it the go-to technology for most condition monitoring strategies.

Yet, a technology with this much capability opens the door for confusion. With this much versatility, users need an easy way to decide which failure modes are best suited to ultrasound. To understand all that is possible, one only needs to ask one simple question:

Does the defect being sought produce **F**riction, **I**mpacting, or **T**urbulence?

If it does, it is a **FIT** for ultrasound.

Ultrasound instruments work on the principle of frequency conversion or heterodyning. They convert high frequency, inaudible sounds into audible sounds while maintaining the integrity of the source. They enable humans to hear sounds they otherwise could not. And what do these sounds have in common? They are created by defects associated with **friction, impacting** and **turbulence**. Here are three examples:

Friction – It shouldn't be the case, but the life span of most bearings is far shorter than its engineered specification. Poor lubrication practices are often the culprit. Lubrication reduces friction, but it remains one of the most abused and misunderstood maintenance practices. Ultrasound instruments measure friction levels and alert maintenance when fresh lubrication is needed. Some instruments have intuitive onboard greasing assistance that prevents over and under lubrication.

Impacting – The best examples of impacting come from bearing defects. Pitting, spalling, misalignment, imbalance and contamination are common. Reliability departments deploy ultrasound as the first line of defense against defects that create impacting.

Turbulence – Compressed air, for example, is expensive to produce, yet 35 to 40 percent of demand is wasted by leaks. Leaks produce turbulent flow (i.e., a hissing sound) at the leak site, but you can't hear it because the plant is too noisy. Ultrasound hears only the leaks and blocks out the rest, no matter how much background noise there is.

The Future of Ultrasound Is Here

Recent innovations are advancing the ways ultrasound is used for determining early stage defects and diagnosing faults in slow speed rotating assets.

Dynamic signal analysis looks at continuous data acquired over a user-defined time frame. This helps diagnose low speed rotating assets and variable frequency drives (VFDs).

The advent of four condition indicators (4CI) changes simple dB trends into sophisticated analysis. 4CI makes static ultrasound data meaningful. Overall, RMS, max RMS, peak and crest factor are cohesive indicators that correlate defects caused by both friction and impacting.

Ultrasound has a significant role in the world of ACM. It performs best in difficult, noisy environments and modern advancements return accurate and repeatable data. Dynamic signal analysis and four condition indicators are innovative game changers for reliability. Their added versatility allows machine diagnosis to be done at an earlier stage by less skilled technicians. This awards freedom to vibration analysts to perform more advanced diagnostics on their most critical assets.

Ultrasound is just one technology in the ACM group, albeit an important one. Used in conjunction with a proper failure mode and effects analysis (FMEA), this condition monitoring (CM) technology contributes meaningfully to the overall reliability goals of any organization pursuing a progressive reliability culture.

ABOUT THE AUTHOR

Allan Rienstra is the President of SDT Ultrasound Solutions and co-author of *Hear More; A Guide to Using Ultrasound for Leak Detection and Condition Monitoring* (www.mrozone.com). He has spent the past 19 years helping manufacturers around the globe establish world class ultrasound programs. His solutions-oriented approach matches client applications with instrument and software selection, implementation training, and continuous coaching. Mr. Rienstra lives in Cobourg, Ontario, Canada with his wife and two sons.

EFFECTIVE ELECTRIC MOTOR TESTING

By Mike Teska

One of the most common critical assets in nearly all asset condition monitoring (ACM) programs is the electric motor. Electric motors are key to driving industrial processes. When electric motor failures occur, they can be very costly, both in terms of the motor repair or replacement itself and the cost of lost production.

An effective ACM program gets its requirements from a completed reliability-centered maintenance (RCM) project, which identifies failure modes to focus on with tests. For the electric motor, the most prevalent failures after bearing failures are electrical insulation failures.

There are two types of electrical insulation in the motor: ground wall insulation and winding insulation. Ground wall insulation keeps the electricity from jumping to the ground. It is often a thick, insulating paper in the stator slots that separates the windings from the motor's stator core. In contrast, the winding insulation is a thin film on the wire that makes up the windings in the stator and keeps the electricity in the windings from jumping to other windings. Both types of insulation are necessary for correct motor performance.

Testing for motor insulation strength is done while the motor is off (i.e., in a static state), during planned shutdowns, while in storage, or in a motor shop. Effective tests of ground wall insulation can be done with direct current (DC) tests. The IEEE and the International Electrotechnical Commission (IEC) both recommend testing of the ground wall insulation at voltages significantly above operating voltage. Why? To ensure there is sufficient margin in the insulation system to handle the kinds of voltage transients present in the power supplied to the motor. These transients in the power system are caused by sudden load variations on the voltage bus, starts and stops of the motor, and variable frequency drives (VFDs).

Effective winding insulation tests require a surge test. This test creates a very fast transient voltage, much like what appears in the power system, to detect weakness in the winding insulation. The fast, transient voltage provided by the surge tester creates sufficient voltage between the wires in the winding to provide an effective test for winding insulation strength. During motor operation, winding insulation faults quickly cause very high currents to flow within the motor windings, usually resulting in melted winding material. This, in turn, burns a hole through the ground wall insulation, also resulting in a ground wall insulation failure. The IEEE and IEC also provide standards for the surge test. Like the DC ground wall tests, surge tests are recommended to be run at voltages significantly higher than the operating voltage, which accounts for the voltages seen in normal power system operations.

Static testing is an effective way to test electric motors. Companies who use this technology often report a return on investment (ROI) of better than 100 percent in the first year. This is due to the avoidance of the high costs of motor failure, the relatively low cost of the test equipment, its ease of use and the effectiveness of the testing.

Results from static testing of electric motors provide a reliable early warning for the potential of electric motor failures. This early warning provides ample time to schedule motor maintenance, avoiding unplanned downtime.

Future trends in electric motor testing include more automation of test result analysis and the use of even more sensitive tests, such as partial discharge measurement during a surge test to provide even earlier indications of motor insulation weakness. These future improvements, built on the solid foundation of today's capabilities, will provide even more effective results for the electric motors in your ACM program.

ABOUT THE AUTHOR

Mike Teska is the product line manager for the SKF Electric Motor Condition Monitoring product lines, formerly Baker Instruments. A graduate of the University of Michigan in electrical engineering, he has over 20 years of experience in test and measurement, including work with HP, Agilent and 8 years with SKF in electric motor test and monitoring. Mike has served as the engineering manager, general manager and product line manager of SKF's Electric Motor Condition Monitoring business. He is active in IEEE motor and insulation groups and has contributed several papers. Outside work, Mike enjoys skiing, hiking, biking, photography and spending time with his family.

AUTHORS

Jack Nicholas, Jr.

Jack Nicholas, Jr. CRL, CMRP, has over 45 years' experience leading, teaching, training and consulting in the fields of maintenance and reliability in government, military, utility and commercial venues in Asia, Australia, North America and the Caribbean. Mr. Nicholas is author, co-author, editor and major contributor to many books, professional papers and magazine articles on maintenance reliability subjects.

Dave Reiber

Dave Reiber, CRL, CMRP, is the Senior Reliability Leader of Reliabilityweb.com. Mr. Reiber has 20 years as a leader in enterprise asset management and asset condition monitoring as the former Global Training Lead for Enterprise Asset Management & Predictive Maintenance Business Lead for General Motors. He is a seasoned international trainer with deep experience in handling diverse cultures and languages. Mr. Reiber received a Chairman's Honor Award for Leading Team in developing global maintenance business process and a CIO award for successful Enterprise Asset Management deployment in Liuzhou, China.

Terrence O'Hanlon

Terrence O'Hanlon, CMRP, Chief Executive Officer of Reliabilityweb.com and Publisher for Uptime® Magazine, is an asset management leader specializing in reliability and operational excellence. He is certified in Asset Management by the Institute of Asset Management and is a SMRP Certified Maintenance & Reliability Professional. Mr. O'Hanlon is a popular keynote presenter with the ability to deliver awareness about the business advantages of asset management to top management.

THANK YOU

SPONSORS

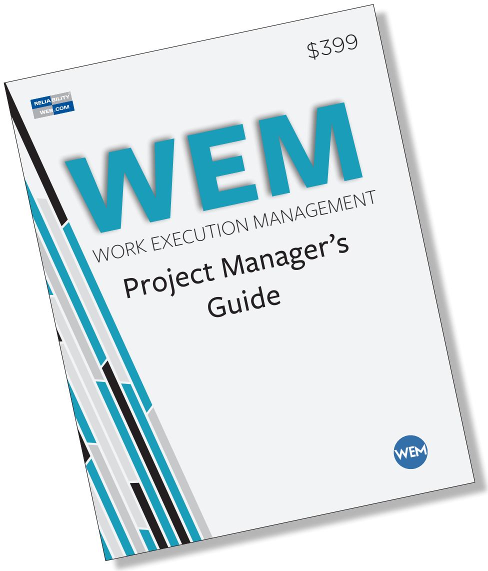
DES-CASE®

PRÜFTECHNIK®

HEAR SDT MORE

SKF®

Project Manager's Guide Series

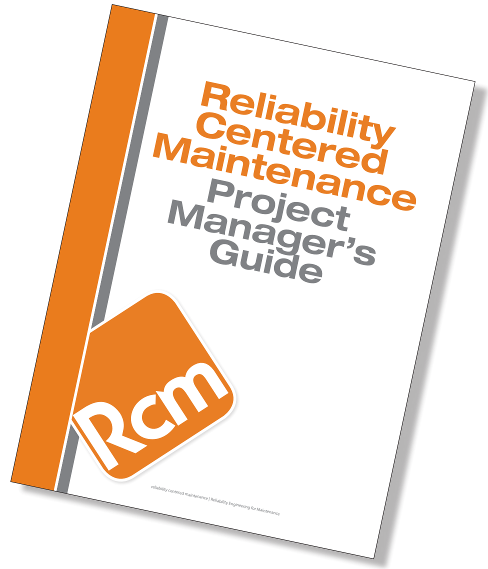


DOWNLOAD

Work Execution Management Project Manager's Guide

DOWNLOAD

Reliability Centered Maintenance Project Manager's Guide



Mapped Services and Training (MSAT) Providers

Reliabilityweb.com has created an ecosystem of reputable solution providers who deliver relevant services and training aligned to Uptime® Elements™ – A Reliability Framework and Asset Management System™.

LUDECA Keep it running. | LCE LIFE CYCLE ENGINEERING | PRÜFTECHNIK | ARMS RELIABILITY EMPOWER | EDUCATE | EQUIP | SDT HEAR MORE | Bentley Advancing Infrastructure | nexus global | THE ULTRASOUND institute

Approved MSAT Providers have knowledgeable service personnel and instructors who maintain the Certified Reliability Leader™ (CRL) certification and are in good standing.

ABOUT RELIABILITYWEB.COM

RELIABILITYWEB.COM

Created in 1999, Reliabilityweb.com provides educational information and peer-to-peer networking opportunities that enable safe and effective maintenance reliability and asset management for organizations around the world.

ACTIVITIES INCLUDE:

Reliabilityweb.com® (www.reliabilityweb.com) includes educational articles, tips, video presentations, an industry event calendar and industry news. Updates are available through free email subscriptions and RSS feeds. **Confiabilidad.net** (www.confiabilidad.net) is a mirror site that is available in Spanish.

Uptime® Magazine (www.uptimemagazine.com) is a bi-monthly magazine launched in 2005 that is highly prized by the maintenance reliability and asset management community. Editions are obtainable in both print and digital.

Reliability Leadership Institute® Conferences and Training Events (www.reliabilityweb.com/events) offer events that range from unique, focused-training workshops and seminars to small focused conferences to large industry-wide events, including the International Maintenance Conference and The RELIABILITY® Conference.

MRO-Zone Bookstore (www.reliabilityweb.com/bookstore) is an online bookstore offering a maintenance reliability and asset management focused library of books, DVDs and CDs published by Reliabilityweb.com.

Association of Asset Management Professionals (www.maintenance.org) is a member organization and online community that encourages professional development and certification and supports information exchange and learning with 50,000+ members worldwide.

A Word About Social Good

Reliabilityweb.com is mission driven to deliver value and social good to the maintenance reliability and asset management communities. Doing good work and making profit is not inconsistent, and as a result of Reliabilityweb.com's mission-driven focus, financial stability and success has been the outcome. For over a decade, Reliabilityweb.com's positive contributions and commitment to the maintenance reliability and asset management communities have been unmatched.

Other Causes

Reliabilityweb.com has financially contributed to include industry associations, such as SMRP, AFE, STLE, ASME and ASTM, and community charities, including the Salvation Army, American Red Cross, Wounded Warrior Project, Paralyzed Veterans of America and the Autism Society of America. In addition, we are proud supporters of our U.S. Troops and first responders who protect our freedoms and way of life. That is only possible by being a for-profit company that pays taxes.

I hope you will get involved with and explore the many resources that are available to you through the Reliabilityweb.com network.

Warmest regards,
Terrence O'Hanlon
CEO, Reliabilityweb.com