Condition Based Maintenance Plus DoD Guidebook

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DEPUTY UNDER SECRETARY OF DEFENSE FOR
LOGISTICS AND MATERIEL READINESS
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FOREWORD

The Department of Defense (DoD) is continually challenged to identify and meet warfighter expectations while making every effort to conduct cost effective sustainment operations. Managing the acquisition and sustainment of DoD weapon systems across the entire life cycle requires focused attention from Service leadership and program managers to develop and implement enhanced support strategies. Condition Based Maintenance Plus (CBM$^+$) policy for the Military Departments and Defense Agencies, established by Department of Defense Instruction (DoDI) 4151.22, dated December 2, 2007, provides an integrated strategy for deployment of enabling technologies, processes, and procedures that focus on a broad range of weapon systems sustainment improvements.

The CBM$^+$ Action Group developed the *CBM$^+$ DoD Guidebook* to be an information reference as well as a tool to assist logistics managers with CBM$^+$ project development, implementation, and execution. As a supplement to the CBM$^+$ DoDI, the Guidebook illustrates various complementary components of successful CBM$^+$ implementation and describes management actions necessary to integrate the technologies in order to increase reliability, availability, operational effectiveness, and maintenance efficiency.

Revisions to this Guidebook will occur as new CBM$^+$ information becomes available. Guidebook access is available on-line at the Assistant Deputy Under Secretary of Defense for Maintenance Policy and Programs (ADUSD[MPP]) web site (http://www.acq.osd.mil/ log/mrmp/CBM+.htm). I encourage sharing the Guidebook across all appropriate communities of interest and promoting its use as a valuable resource during the design, acquisition, and sustainment of DoD weapon systems and equipment.

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Section 1.
Introduction to CBM+

Definition

Condition Based Maintenance Plus (CBM+) is the application and integration of appropriate processes, technologies, and knowledge-based capabilities to improve the reliability and maintenance effectiveness of DoD systems and components. At its core, CBM+ is maintenance performed based on evidence of need provided by Reliability Centered Maintenance (RCM) analysis and other enabling processes and technologies. CBM+ uses a systems engineering approach to collect data, enable analysis, and support the decision-making processes for system acquisition, sustainment, and operations.[1]

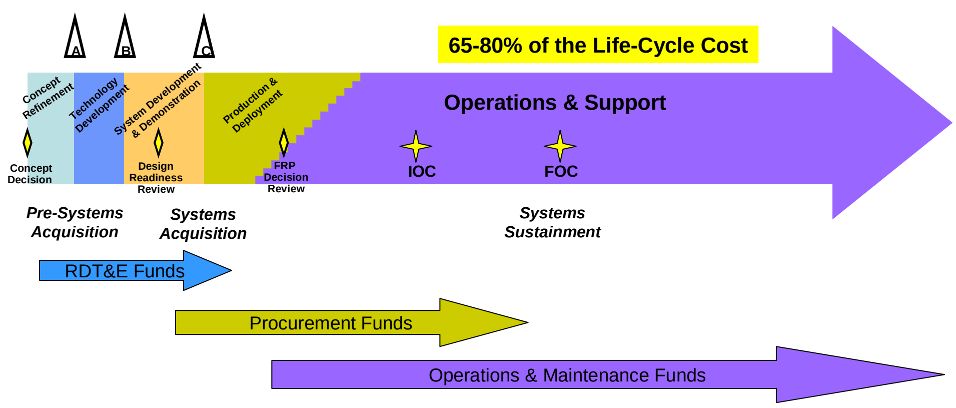
Why Change?

A number of changes in the world situation, business management, and emerging technologies have resulted in major changes to National Defense Strategy. In response to these changes, the Secretary of Defense has said, “We will continually adapt how we approach and confront challenges, conduct business and work with others.[2] More specifically, the Secretary has stated:

> Forces employing transformational warfighting concepts require transformed supporting processes that produce the timely results demanded by 21st century security challenges. Senior leadership must take the lead in fostering innovation and adaptation of information age technologies and concepts.[3]

The life-cycle impact is clear when operations and support (O&S) costs are compared to total ownership costs, as shown in Figure 1-1.

Figure 1-1. O&S Costs



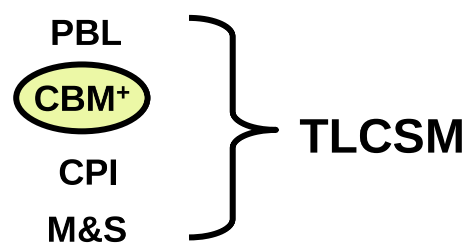
[1] DoD Instruction 4151.22, *Condition Based Maintenance Plus for Materiel Maintenance*, December 2, 2007.

[2] Secretary of Defense, *National Defense Strategy 2005*, March 2005.

[3] Secretary of Defense, *Transformational Planning Guidance 2003*, April 2003.

DoD has identified warfighter expectations and made an effort to conduct support operations in a more effective as well as fiscally responsible manner. Under the umbrella of Total Life Cycle System Management (TLCSM), the sustainment of a weapon system receives increased attention from Service leadership and program managers. TLCSM establishes clear responsibilities and accountability for meeting warfighter expectations. It sets goals, tracks progress and status, and balances resources to accomplish desired material readiness. CBM$^+$, in concert with the other TLCSM tools (Continuous Process Improvement [CPI], cause-and-effect predictive modeling and simulation [M&S], and desired outcomes achieved through Performance Based Logistics [PBL]), will enhance materiel readiness. Figure 1-2 displays the relationship of these tools to TLCSM.

Figure 1-2. Logistics Efforts That Support TLCSM



CBM$^+$ supports the larger DoD improvement efforts of the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD[AT&L]), with the goal of delivering cost-effective joint logistics performance by maximizing weapon system and equipment availability through a more effective logistics process. The strategy fully supports these broad, long-term goals articulated in the AT&L Strategic Goals Implementation Plan:[4]

- A high-performing, agile, and ethical workforce
- Strategic and tactical acquisition excellence
- Focused technology to meet warfighting needs
- Cost-effective joint logistics support for the warfighter
- Reliable and cost-effective industrial capabilities sufficient to meet strategic capabilities
- Improved governance and decision processes
- Capable, efficient, and cost-effective installations.

To satisfy these goals and achieve its future materiel maintenance requirements, DoD must

- enhance materiel availability at the best possible cost by establishing integrated, predictive maintenance approaches that minimize unscheduled repairs;
- eliminate unnecessary maintenance activity; and
- employ the most cost-effective maintenance health management approaches.

[4] USD(AT&L), *Strategic Goals Implementation Plan for FY2007*, November 2006.

To meet these challenges, DoD management is paying specific attention to CBM$^+$ to ensure its timely implementation in new acquisition programs and across the sustainment life cycle for DoD weapon systems and equipment.

CBM$^+$ History

CBM$^+$ was originally developed as a DoD initiative to provide a focus for a broad variety of maintenance improvements that would benefit both the maintainer and the warfighter. It was established to expand upon condition-based maintenance (CBM) and encompass other technologies, processes, and procedures that enable improved maintenance and logistics practices.[5]

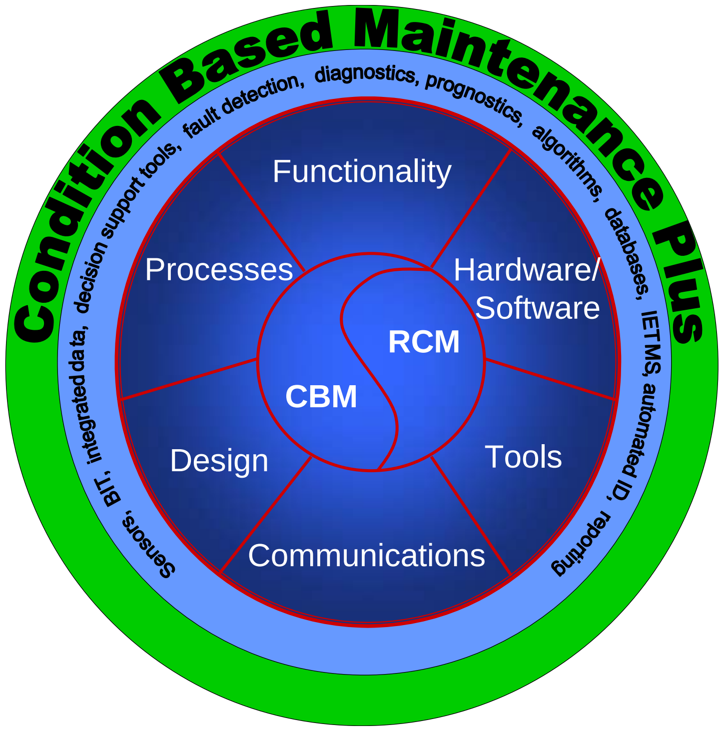
CBM is an established approach to identifying and scheduling maintenance tasks. It employs continuous or periodic assessment of weapon system condition using sensors or external tests and measurements through first-hand observation or portable equipment. The goal of CBM is to perform maintenance only when there is evidence of need. Synergy from integrating the enabling CBM$^+$ capabilities builds upon the foundation of CBM. CBM$^+$ continues to evolve from this original concept into the maintenance improvement strategy that is discussed in this Guidebook.

CBM$^+$ includes a conscious effort to shift equipment maintenance from an unscheduled, reactive approach at the time of failure to a more proactive and predictive approach that is driven by condition sensing and integrated, analysis-based decisions. CBM$^+$ focuses on inserting technologies that improve maintenance capabilities and processes into both new and legacy weapon systems and integrates the support elements to enable enhanced maintenance-centric logistics system responses. With more accurate predictions of impending failures (based on real-time condition data), coupled with more timely and effective repairs, moving toward CBM$^+$ will result in dramatic savings—in time and money—and improved weapon system availability and performance. CBM$^+$ uses modern maintenance tools, technologies, and processes to detect the early indications of a fault or impending failure to allow time for maintenance and supply channels to react and minimize the impact on system operational readiness and life-cycle costs. CBM$^+$ provides a means of optimizing the approach to maintenance, and is a vehicle to reduce scheduled maintenance requirements. The flexibility and optimization of maintenance tasks with CBM$^+$ also reduces requirements for maintenance manpower, facilities, equipment, and other maintenance resources.

CBM$^+$ is not a single process in itself. It is a comprehensive strategy to select, integrate, and focus a number of process improvement capabilities, thereby enabling maintenance managers and their customers to attain the desired levels of system and equipment readiness in the most cost-effective manner across the total life cycle of the weapon system. CBM$^+$ includes a variety of interrelated and independent capabilities and initiatives—some procedural and some technical—that can enhance basic maintenance tasks. At its core, CBM$^+$ is maintenance performed upon evidence of need provided by RCM analysis and other enabling processes and technologies. Advanced engineering, maintenance, and information system technologies, as well as contemporary business processes that underpin CBM$^+$, fit in categories as shown in Figure 1-3.

[5] Deputy Under Secretary of Defense (Logistics and Materiel Readiness), Memorandum for the Secretaries of the Military Departments, "Condition Based Maintenance Plus," November 25, 2002.

Figure 1-3. CBM+ Overview



CBM+ includes, but is not limited to, the following examples:

- *Hardware*—system health monitoring and management using embedded sensors; integrated data bus
- *Software*—decision support and analysis capabilities both on and off equipment; appropriate use of diagnostics and prognostics; automated maintenance information generation and retrieval
- *Design*—open system architecture; integration of maintenance and logistics information systems; interface with operational systems; designing systems that require minimum maintenance; enabling maintenance decisions based on equipment condition
- *Processes*—RCM analysis; a balance of corrective, preventive, and predictive maintenance processes; trend-based reliability and process improvements; integrated information systems providing logistics system response; CPI; Serialized Item Management
- *Communications*—databases; off-board interactive communication links
- *Tools*—integrated electronic technical manuals (i.e., digitized data) (IETMs); automatic identification technology (AIT); item-unique identification; portable maintenance aids (PMAs); embedded, data-based, interactive training
- *Functionality*—low ambiguity fault detection, isolation, and prediction; optimized maintenance requirements and reduced logistics support footprints; configuration management and asset visibility.

Achieving More Effective Maintenance

To satisfy the requirements of a changing National Defense Strategy, maintenance managers are challenged to apply CPI[6] concepts and tools to improve maintenance agility and responsiveness. The goal is to increase operational availability and readiness and to reduce life-cycle total ownership costs by performing only the required repairs at the optimum time, and by reducing stocks of spares and repair parts to support maintenance operations. CBM+ supports these objectives by encouraging the Services to employ health monitoring technology and reliability analysis, such as RCM, to optimize operations and supportability of major systems. More effective maintenance requires a change in the culture of the maintenance community from a primarily reactive maintenance philosophy to a proactive, planned maintenance philosophy. In this sense, initiatives like CBM+ must adopt a dynamic approach for evolving a set of capabilities, as opposed to perfect planning, development of comprehensive requirements, or comprehensive reengineering.

CBM+ initiatives include fully developed technologies and processes that can be implemented now as well as yet-to-be developed capabilities. CBM+ also uses proof-of-concept and prototype activity that can be applied incrementally, not waiting for a single solution package. To maintain consistency, CBM+ development should be based on a broad architecture and an enterprise framework that is open to modification and can be easily adjusted.

Goals of CBM+

CBM+ represents a continuous development of maintenance processes and procedures that improve capabilities, practices, and technologies. CBM+ is a part of the transformation of maintenance practices from the Industrial Age to the Information Age through the appropriate use of emerging technologies to analyze near-real-time and historical weapon systems data to provide a predictive maintenance capability. The challenge of CBM+ is to provide tangible effects to DoD operations across all categories of equipment.

CBM+ is an opportunity to improve business processes, with the principal objective being improved maintenance performance across a broad range of benefits, including greater productivity, shorter maintenance cycles, lower costs, increased quality of the process, better availability, and enhanced reliability of materiel resources.

Under the TLCSM concept, four metrics have been established as life-cycle sustainment outcome metrics, and they are appropriate to use when evaluating CBM+ implementation. The metrics are defined as follows:

- Materiel availability (MA)[7] is a measure of the percentage of the total inventory of a system that is operationally capable (ready for tasking) of performing an assigned mission at a given time, based on materiel condition. It can be expressed mathematically as the number of operational end items divided by the total population.

[6] Office of the Secretary of Defense, *Continuous Process Improvement Transformation Guidebook*, May 2006.

[7] As referenced in the Chairman Joint Chiefs of Staff Manual (CJCSM) 3170.01, materiel availability is a key performance parameter (KPP) associated with the key system attributes (KSAs) of materiel reliability and ownership costs.

Materiel availability also indicates the percentage of time a system is operationally capable of performing an assigned mission, and can be expressed as uptime divided by the sum of uptime and downtime.

- Materiel reliability (MR) is a measure of the probability the system will perform without failure over a specific interval. Reliability must be sufficient to support the warfighting capability needed. Materiel reliability is generally expressed in terms of a mean time between failures (MTBF), and, once operational, can be measured by dividing actual operating hours by the number of failures experienced during a specific interval.

- Ownership cost (OC) balances the sustainment solution by ensuring the O&S costs associated with materiel readiness are considered when making decisions. For consistency, and to capitalize on existing efforts in this area, the Cost Analysis Improvement Group's O&S Cost Estimating Structure supports this key system attribute.

- Mean down time (MDT) is the average total time required to restore an asset to its full operational capabilities. MDT includes the time from reporting of an asset being down to the asset being given back to operations or production to operate.[8]

The relationship between various CBM$^+$ objectives and these metrics is shown in Table 1-1.

Table 1-1. CBM$^+$ Objectives and Metrics

	MA	MR	OC	MDT
Enhance maintenance effectiveness with integrated maintenance and logistics systems	X			X
Incorporate advanced engineering, maintenance, logistics/supply chain, configuration management, and information technologies		X		
Employ weapon system designs that use measurable, consistent, and accurate predictive parameters from embedded CBM$^+$ capabilities		X		
Improve data about maintenance operations and parts/system performance	X			X
Improve advanced diagnostics, system prognostics, and health management capabilities based on current condition data	X	X	X	X
Provide more accurate item tracking capabilities				X
Reduce maintenance requirements by performing maintenance tasks only upon evidence of need (more proactive/predictive, less preventive and less corrective)	X		X	
Enable more effective maintenance training				X
Create a smaller maintenance and logistic footprint			X	
Improve maintenance capabilities, business processes, supply/maintenance planning, and responsiveness leading to optimum weapon system availability				X
Minimize unique support equipment and information systems for individual weapon systems			X	
Improve system maintainability as a part of design modification through the use of reliability analysis		X		X
Provide interoperability/jointness to the warfighter	X		X	

[8] Mean down time has been identified as an important metric to measure operational availability.

All desired readiness improvement technology enhancement, readiness, or new process improvements must be developed or acquired. This includes the use of resources that are always limited. Even with a policy that requires its implementation, CBM$^+$ has to "buy its way" into the program. Service leadership and the program and support managers want to do the right thing for the warfighter, but a return on the investment must be identified and justified. In the long run, any Service effort to develop and deploy CBM$^+$ should be leveraged by other platforms and programs.

Benefits of CBM$^+$

This Guidebook brings together many different ingredients required for a successful CBM$^+$ strategy. CBM$^+$ focuses on applying technology that

- improves maintenance capabilities and business processes;
- complements and enhances DoD-wide reliability analysis efforts;
- involves the integration of support elements to enable enhanced maintenance-centric logistics system response; and
- facilitates more accurate predictions of impending failures (based on condition data), resulting in dramatic savings and improved weapon system availability, ultimately benefiting the warfighter.

This Guidebook also describes the actions necessary to integrate these component elements into an operational capability for more effective and efficient support of the operational customer—the warfighter. The benefits to the warfighter can best be described within the context of three levels (tactical, operational, and strategic):[9]

- At the tactical level, CBM$^+$ may mean new tools, test equipment, and embedded onboard diagnostics. These tools take advantage of current and emerging commercial and diagnostic technologies that translate system condition data (such as temperature, vibration, cycle-time) in combination with environmental factors (like desert, arctic, and high humidity) into proactive maintenance actions that are performed only when there is evidence of actual need. With CBM$^+$, maintainers can convert weapon system or equipment condition data into proactive maintenance actions. Scheduled inspections are supplemented or replaced because maintainers will have analytical data that describe the condition of the weapon system and its components.
- To the commander at the operational level, CBM$^+$ brings the ability to meet mission requirements and increase weapon system availability. CBM$^+$ provides commanders, mission planners, and logistics providers with information that enables better maintenance decision making and mission assignment. CBM$^+$ supports Focused Logistics by enhancing command situational awareness at the weapon system level.

[9] Levels are defined in CJCSM 3500.04D, *Universal Joint Task List*, 1 August 2005, Enclosure B, Appendix A.

- While some CBM^+ features are installed at individual platform level, the benefits of CBM^+ are most effectively achieved when an entire fleet is incorporated and the information is leveraged. At the strategic level, CBM^+ identifies maintenance actions based on a near-real-time assessment of equipment status from diagnostic sensors and equipment. Data collected from embedded sensors, such as health and usage monitoring systems are then translated into predictive trends or metrics that anticipate when component failures will occur and identifies components that may require redesign or replacement to reduce high-failure rates. Common use of items and data among the Services on like-systems will greatly reduce logistics footprints and costs.

CBM^+ End State Vision

The Services have been directed to incorporate their CBM^+ strategies into appropriate guidance and directives to ensure implementation in organic (i.e., DoD in-house) maintenance capabilities and operations as well as in commercially supported DoD systems and programs for both new and legacy weapon systems. Institutionalization of the CBM^+ strategy in relevant regulatory publications is the first step toward attaining the ultimate end state. The envisioned CBM^+ operational environment will occur from the individual component to the platform level, in training courses, and the deployed environment. Initially, Defense Acquisition Programs will exploit CBM^+ opportunities as elements of system performance requirements during the design and development phase and throughout the life cycle.

Once implemented, CBM^+ will be the primary reliability driver in DoD's TLCSM supportability strategy. In concert with the other TLCSM enablers (such as CPI, cause-and-effect predictive modeling, and desired outcomes achieved through PBL), the implemented CBM^+ strategy will help optimize key performance measures of materiel readiness—MA, MR, MDT, and OC. Ideally, the desired CBM^+ end state is a trained force of maintainers from the tactical field technician to the strategic system analyst working in an interoperable environment to maintain complex systems through the use of CBM^+ processes and technologies. Fully implemented CBM^+ improves maintenance decisions and helps integrate all functional aspects of life-cycle management processes (such as acquisition, distribution, supply chain management, and system engineering).

How to Use This Guidebook

CBM^+ is a key component of the CPI initiative. This Guidebook should be used as a reference to assist those interested in learning more about the CBM^+ strategy and, more particularly, those charged with implementation of CBM^+ as a CPI initiative to improve maintenance and related processes. The Guidebook presents key elements and implementation strategies for achieving incorporation of CBM^+ enablers into the DoD maintenance process.

The Guidebook is designed to allow the reader to research subject matter based upon their experience or knowledge level and expertise in CBM+:

- Section 2 is a CBM+ primer ("What is CBM+?" and "Why is it important?") and provides background and examples of CBM+ initiatives.
- Section 3 outlines the essential elements of CBM+ and how it can be implemented effectively. Section 3 should be used as a reference for maintenance managers just getting acquainted with CBM+.
- Section 4 summarizes the basic implementation steps for a CBM+ initiative or project with examples of enabling technologies, tools, and best practices referenced in Attachment A.
- Section 5 describes the basic management approach for CBM+, and is intended for use by the experienced CBM+ manager.
- Section 6 summarizes the basic metrics to be used for any CBM+ initiative.

Each section of the Guidebook starts with a checklist of potential points or questions that relate to the subject matter. These checklists have been prepared at a high level for use by the CBM+ implementer as a reference. The basic content of the checklists form a "game plan" to assist the readers in formulating their own CBM+ implementation strategies tailored to their particular requirements and objectives.

The Guidebook does not contain an in-depth description of all possible details regarding CBM+ implementation. It will be useful to the CBM+ implementer in selecting and adopting a broad range of enabling hardware, software, and other tools necessary to facilitate maintenance improvement efforts.

Anyone interested in learning more about this subject should also review the following:

- Attachment A provides additional detail regarding applicable CBM+ technologies, enabling tools, and best practices.
- The Materiel Readiness Senior Steering Group through a supporting Action Group (AG) monitors and coordinates the CBM+ strategy through research and projects. The CBM+ AG Charter
  - encourages new maintenance technologies and processes;
  - investigates CBM+ efforts in selected Service programs;
  - reviews Service CBM+ plans;
  - shares and tracks CBM+ information and highlights CBM+ activities across both DoD and the commercial sector.

- A CBM$^+$ baseline was established by an LMI survey of select DoD programs within the Services to identify the CBM$^+$ technologies and tools of most interest to the program managers and limited discussions with commercial firms. [10] To view the above report and to obtain the most current information on the DoD's CBM$^+$ initiative and the CBM$^+$ AG, see http://www.acq.osd.mil/log/mppr/CBM%2B.htm.

This Guidebook is an evolving document, as more individuals and organizations focus on improving the maintenance process through new technologies, practices, and processes. Comments and suggestions to improve this Guidebook are welcome at atl.mppr@osd.mil.

[10] LMI, *CBM$^+$ Survey of Select Programs*, Report LG301T6, D. Cutter and O. Thompson, January 2005.

Section 2.
Background of CBM^+

Table 2-1 summarizes the essential information regarding the requirements for an effective CBM^+ strategy.

Table 2-1. CBM^+ Background Checklist

1.	Have I thoroughly reviewed the CBM^+ introductory materials in Section 1 and the additional references in Attachment B to fully understand the basis for developing a CBM^+ strategy?
2.	Do I have sufficient background information on CBM^+ to assess the current maintenance program in my organization regarding this strategy?
3.	Does the CBM^+ implementation team fully understand the reasons for transitioning from current maintenance approaches to an CBM^+ environment?
4.	Is additional research needed to familiarize myself and team members with CBM^+ background, policies, technologies, or other relevant information?
5.	Do I have adequate training for the team?
6.	Have I reviewed ongoing DoD and Service CBM^+ programs to understand the status, characteristics, and issues associated with these efforts?

Traditional Maintenance

Maintenance programs for DoD materiel are structured and managed to achieve inherent performance, safety, and reliability levels of the materiel. Maintenance tasks restore safety and reliability to their required levels when deterioration has occurred. Maintenance programs are structured for meeting the readiness and sustainability objectives (including mobilization and surge capabilities) of National Defense Strategy and contingency requirements. DoD maintenance activities employ concepts that optimize process technologies, organizational structures, and operating concepts to deliver efficient and effective performance to the operating forces based on strategic and contingency planning.[1]

How Is Maintenance Accomplished Today?

Maintenance can be performed using a wide variety of approaches. Two main categories of maintenance—reactive and proactive—describe the full range of options available.

- Reactive maintenance (also called corrective maintenance) is performed for items that are selected to run to failure or those that fail in an unplanned or unscheduled manner. An item may be on a schedule for periodic maintenance, but if it fails prematurely, it will require maintenance to fix. Reactive maintenance of a reparable item is almost always unscheduled in the sense the failure occurred unpredictably. Reactive maintenance restores an item to a serviceable condition after the failure has occurred.

[1] DoD Directive 4151.18, *Maintenance of Military Materiel*, March 31, 2004.

- Proactive maintenance is considered either preventive or predictive in nature, and the maintenance performed can range from an inspection, test, or servicing to an overhaul or complete replacement:

  - Preventive or scheduled maintenance can be based on calendar time, equipment-operating time, or a cycle (such as number of starts, air vehicle landings, rounds fired, or miles driven). Preventive maintenance may be either scheduled or unscheduled; that is, it is initiated based on predetermined intervals or, alternatively, triggered after detection of a condition that may lead to failure or degradation of functionality of the weapon, equipment, or component.

  - Predictive maintenance can be categorized as either diagnostic or prognostic. Diagnostic identifies an impending failure, while prognostics add the capability to forecast the remaining equipment life. Knowing the remaining life is an obvious benefit to enable optimum mission and maintenance planning.

References for applicable maintenance terms are in DoD Directive 4151.18, “Maintenance of Military Materiel,” and are included in DoD Instruction 4151.22 “Condition Based Maintenance Plus for Materiel Maintenance.”

The life of equipment will be extended if proactive maintenance is performed on weapon systems, equipment, and components as the designer envisioned. Proactive maintenance, like lubrication and filter changes, or even more extensive replacement of failure causing parts, will generally allow the equipment to run more efficiently and last longer, resulting in savings and greater readiness. While it will not prevent all catastrophic end item failures, proactive maintenance will decrease the number of failures and overall equipment downtime. Minimizing these failures translates into savings in both maintenance and future capital equipment replacement costs. Because of the inherent randomness of individual item failures, proactive maintenance cannot eliminate all failures. When failure does occur, corrective maintenance will be required.

Reactive and Proactive Maintenance Approaches

Figure 2-1 illustrates the range of maintenance approaches that can be used to structure maintenance programs, including CBM as a part of a predictive maintenance process.

Figure 2-1. Range of Maintenance Approaches

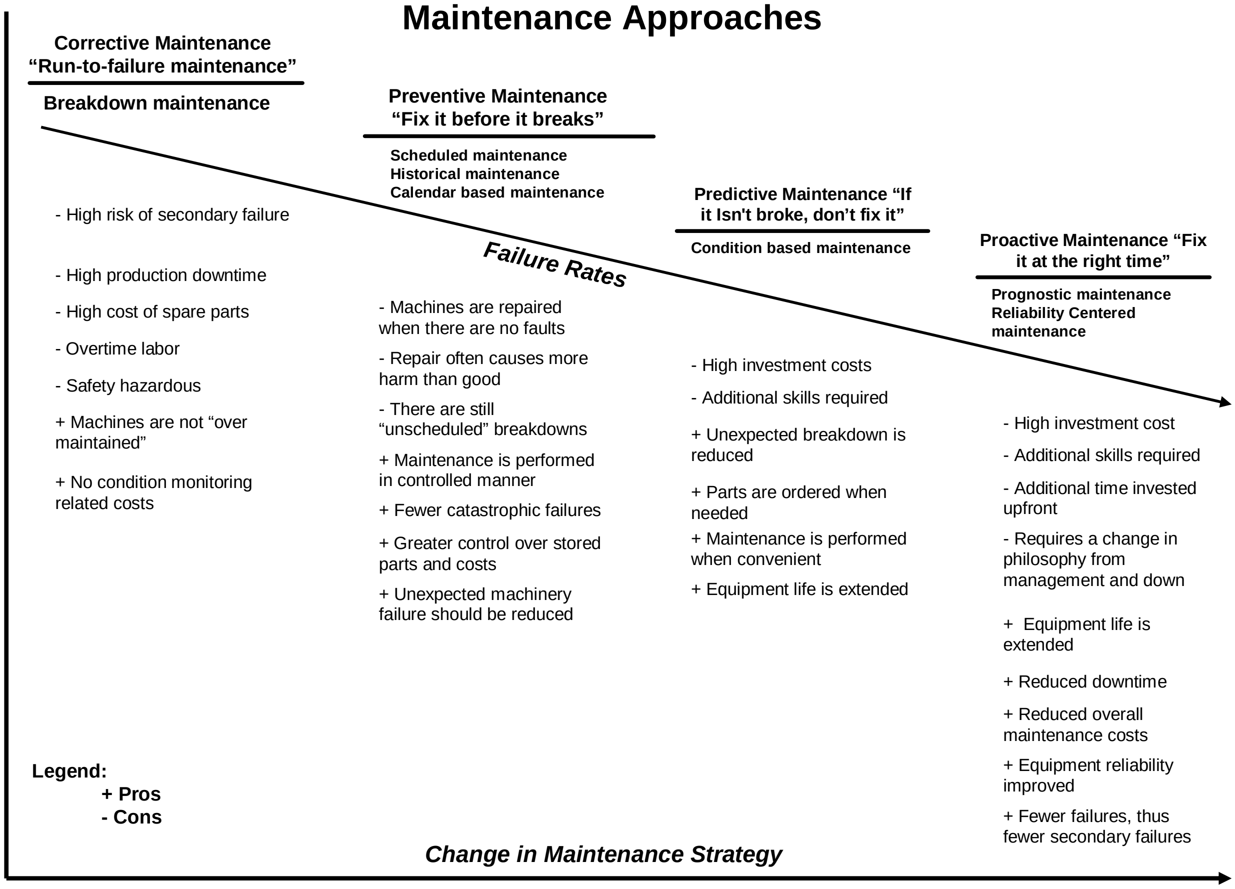
	Maintenance Approaches			
	Reactive	Proactive		
Category	Run-to-fail	Preventive	Predictive	
Sub-Category	Fix when it breaks	Scheduled maintenance	Condition-based maint.-diagnostic	Condition-based maint.- prognostic
When Scheduled	No scheduled maintenance	Maintenance based on a fixed time schedule for inspect, repair and overhaul	Maintenance based on current condition	Maintenance based on forecast of remaining equipment life
Why Scheduled	N/A	Intolerable failure effect and it is possible to prevent the failure effect through a scheduled overhaul or replacement	Maintenance scheduled based on evidence of need	Maintenance need is projected as probable within mission time
How Scheduled	N/A	Based on the useful life of the component forecasted during design and updated through experience	Continuous collection of condition monitoring data	Forecasting of remaining equipment life based on actual stress loading
Kind of Prediction	None	None	On- and off-system, near-real-time trend analysis	On- and off-system, real-time trend analysis

In the past, the alternative to reactive maintenance has most often been time-driven or scheduled maintenance. Under this approach, major maintenance occurs based on pre-determined time intervals generally expressed in months or other time periods. Maintenance actions are triggered primarily by time intervals that are based on average historical failure rates, engineering estimates, or predetermined time cycles. Many current maintenance activities rely on time or operation intervals for services that are labor intensive and fail to address specific conditions driven by environmental and operational factors. While time-driven maintenance is the easiest to schedule, it fails to account for unexpected failures and does not incorporate the possible benefits of manual or automated condition inspection. Time-driven maintenance attempts to attain a predictive approach to maintenance, but it falls short of a true predictive strategy triggered by assessment of actual equipment condition.

Although there are multiple approaches to accomplishing maintenance of weapons and equipment, DoD sustainment policies prescribe greater reliance on proactive, predictive strategies, such as providing the best use of available resources to achieve maximum operational readiness of weapons and equipment. Each approach to maintenance has positive and negative aspects. For example, preventive maintenance or timed component change outs may not reduce failures, but they could reduce maintenance requirements and increase operational availability.

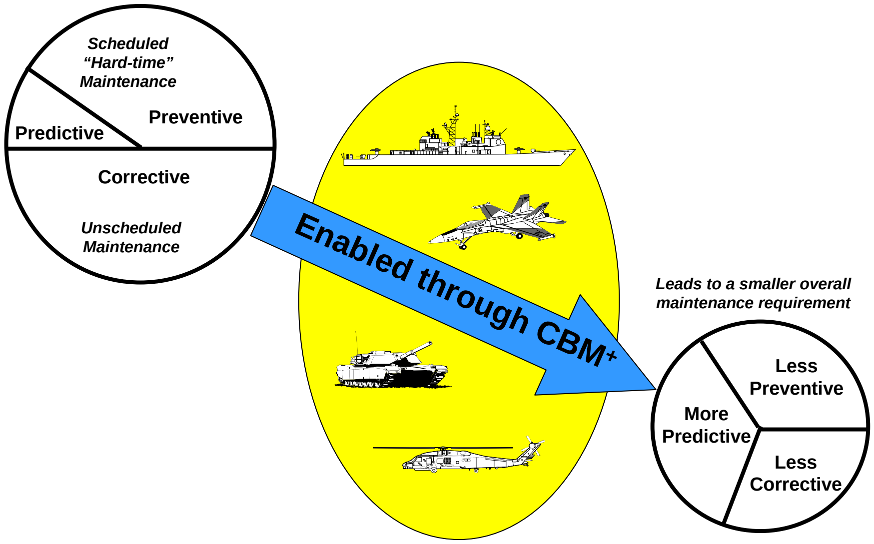
Based on equipment characteristics and environment, any one of these approaches may be useable. Generally, however, the transition to more effective and proactive maintenance strategies will lead to fewer actual equipment failures and corresponding increases in overall equipment life and reduced total life-cycle costs. Figure 2-2 demonstrates this objective.

Figure 2-2. Evolution of Maintenance Strategy



Using the family of capabilities under CBM+ will improve the detection, prediction, and pre-failure reaction to potential failure-causing conditions. Therefore, CBM+ is a valuable tool in improving the greater use and increased effectiveness of preventive maintenance programs. A basic intent of this Guidebook is to facilitate DoD’s evolution toward greater application of the predictive approaches to maintenance using the capabilities inherent in the CBM+ strategy. Figure 2-3 depicts the overarching concept of reducing the total maintenance requirement by incorporating CBM+ technologies and practices. Through the CBM+ process, the equipment’s maintenance plan is modified to include more predictive and less scheduled preventive and corrective maintenance steps.

Figure 2-3. Maintenance Strategy Transition.



Examples of Component CBM+ Initiatives

Considerable progress has already been made by the Military Services in various aspects of CBM+ implementation. Many of these efforts were captured in a 2005 survey of ongoing and planned CBM+ initiatives.[2] This survey identified programs that were distinguished by their active approach to using CBM+ technologies, processes, and procedures. The resulting Service input included fielded and future programs, and several broad maintenance initiatives that are not platform-unique. The following is a short summary of select programs discussed in the referenced survey.

Army

- *Future Combat Systems/Unit of Action* is a suite of 18 manned and robotic air and ground vehicles. Systems are planned to be introduced incrementally between 2008 and 2014.
- The *Stryker* program comprises a family of more than 2,000, 19-ton wheeled armored vehicles in 10 configurations and is being fielded. Most of the Stryker CBM+ elements are still being developed.
- *AH-64 Apache* involves a fleet of more than 700 A- and D-model attack helicopters that have been in service up to 20 years. An A-to-D upgrade program is in progress.

Navy

- *Maintenance Effective Review* incorporates a Naval Sea System Command continuous process that applies reliability-centered maintenance to current maintenance practices and validates ship maintenance requirements.

[2] LMI, *CBM+ Survey of Select Programs*, Report LG301T6, D. Cutter and O. Thompson, January 2005.

- *Engineering for Reduced Maintenance* comprises a family of initiatives (including labor-saving technologies, tools, paints, and diagnostics and prognostics) that are used to extend maintenance periods or eliminate a maintenance requirement.

- *Integrated Condition Assessment System* is an online automated machinery condition monitoring and assessment program currently installed on ships across 12 classes.

Air Force

- *C-17 Globemaster III* is a fleet of 120 strategic transport aircraft (still in production; 180 are planned).

- The *Joint Strike Fighter* program involves a family of more than 2,000 strike fighter aircraft for the Navy, Air Force, Marine Corps, and U.S. allies, with three variants planned for an initial fielding in 2010.

Marine Corps

- *Expeditionary Fighting Vehicle*, formerly the Advanced Amphibious Assault Vehicle, is a fleet of more than 1,000 tracked vehicles, with two variants planned for initial fielding in 2008.

- *Light Armored Vehicle* is a fleet of more than 700, 11 to 14-ton wheeled vehicles in eight configurations. A service life-extension program is in progress.

Defense Logistics Agency

- *Service Parts Ordering Tool* is a logistics research and development initiative that added an electronic parts-ordering capability to the IETMs for the Air Force E-3 Sentry airborne early warning aircraft at Tinker Air Force Base, Oklahoma, and the Naval Sea Systems Command's Virtual Exercise Mine Simulator in Ingleside, Texas.

- *Reliability Initiative* has funded more than 75 projects to develop and insert technology, mainly in support of aging aircraft.

Updates

The occasion and feasibility to apply or insert CBM$^+$ technologies and processes varies with the maturity and complexity of the weapon systems and platforms, the resources available to accomplish individual initiatives, and the operational performance experienced in the field. Service CBM$^+$ projects are continually being revised and updated. Updated information can be found on individual Service websites or the Office of the Secretary of Defense CBM$^+$ website: http://www.acq.osd.mil/log/mppr/CBM%2B.htm.

Section 3.
Essential Elements of CBM^{+}

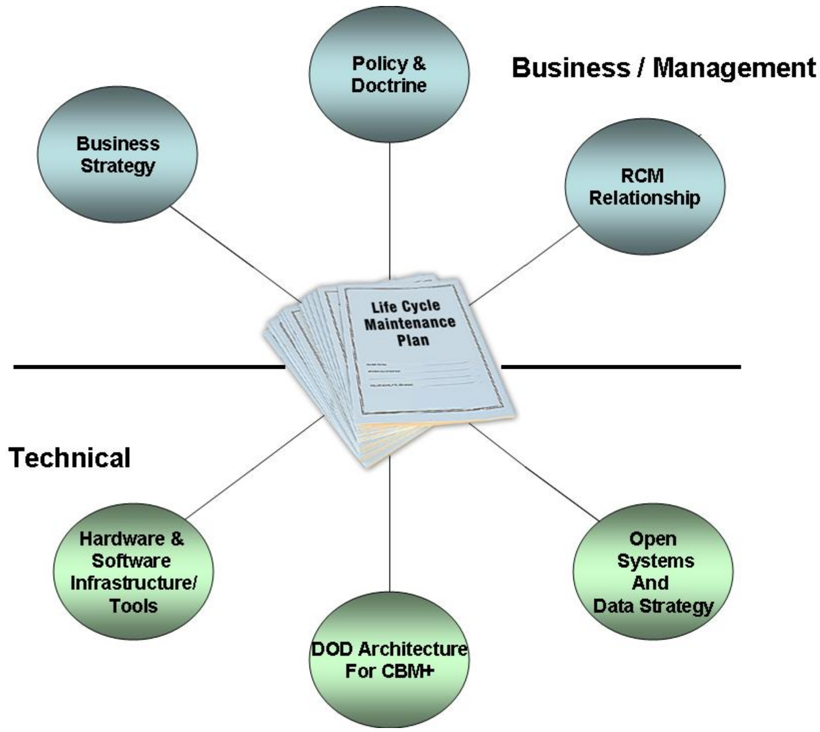
Table 3-1 summarizes the basic components of a comprehensive CBM^{+} strategy.

Table 3-1. Essential Elements Checklist

1. Understand that CBM^{+} elements are categorized into two primary groups: business/management and technical.
2. Recognize and understand the primary groups are divided into six subcategories: <u>Business/Management</u> — <u>Technical</u> Policy and doctrine — CBM^{+} infrastructure Business strategy — DoD architectural framework for CBM^{+} CBM^{+} and RCM — Open systems and data strategy.
3. Policy and doctrine: Recognize the guidance from senior DoD and Service management covering the requirement to implement the CBM^{+} strategy, the objectives and benefits of the effort, who is responsible, and the target end state.
4. Business strategy: Identify the business needs for improving the assessment and satisfaction of the maintenance requirements that drive the need for CBM^{+}, and the approach to accomplishing the CBM^{+} business case.
5. Relationship of CBM^{+} to RCM: Implement the interactive relationship between RCM, as the defining process for determining the most effective maintenance strategies, and CBM^{+}, as the source of methods and technologies to execute the selected maintenance approaches.
6. CBM^{+} infrastructure: Acquire the hardware, software, and human interface components of the CBM^{+} strategy. The infrastructure is the physical building block that must be available to CBM^{+} implementers to construct an operational CBM^{+} approach to CBM.
7. DoD Architectural Framework (DoDAF) for CBM^{+}: Use the DoD standard methodology for building and using a structured design for describing the components and interfaces of the overall CBM^{+} strategy. The architecture provides a holistic tool for constructing a comprehensive picture of the entire CBM^{+} strategy.
8. Open systems and data strategy: Acquire technical capabilities and procedures available to CBM^{+} implementers to accomplish the most effective integration of hardware and software, and data management components of a CBM^{+} strategy. These involve the use of existing commercial and government standards to facilitate interfaces among hardware data collection and storage devices, analytical and communications software, and condition monitoring data repositories.

Implementation of CBM^{+} in DoD activities requires a comprehensive understanding of the numerous elements involved and a realization that successful execution of CBM^{+} must be accomplished in an integrated fashion, incorporating all, or at least most, of the key components of the total strategy. This section describes the basic elements of CBM^{+} in a structured way and attempts to convey the relationships and interactions among these elements. CBM^{+} elements can be categorized into two primary categories—business/management and technical—and six subgroups within these two categories. All the CBM^{+} elements contribute to the development of the maintenance plan across the whole life cycle of the weapon system or platform. The six sub-groupings are shown in Figure 3-1.

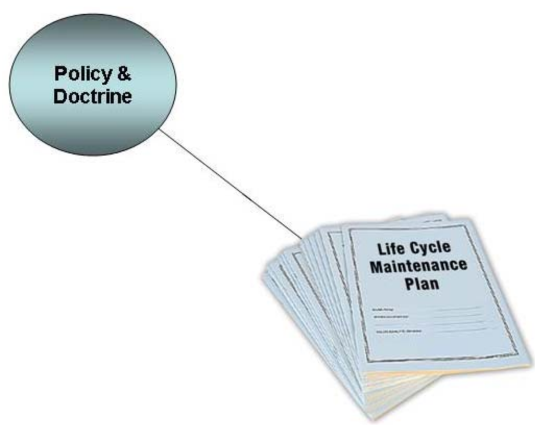
Figure 3-1. CBM+ Element Primary and Sub-Groups



Business/Management

Business/Management includes areas that govern or guide the activities needed to implement and operate a CBM+ strategy in support of a DoD maintenance program. These areas include CBM+ policy and doctrine, business strategy, and the RCM relationship.

1. CBM+ Policy and Doctrine



As a DoD strategy, CBM+ empowers the Services and their program managers to pursue and incorporate maintenance technologies and processes to more effectively support the warfighter. CBM+ improves system supportability, leads to more efficient business processes, and transforms the maintenance environment for both new and legacy systems.

Initial CBM+ Policy Memorandum

The CBM+ strategy was originally promulgated as DoD policy in a memorandum signed by the Deputy Under Secretary of Defense (Logistics and Materiel Readiness) in November of 2002. This memorandum directs that CBM+ be "implemented to improve maintenance agility and responsiveness, increase operational availability, and reduce life cycle total ownership costs." The policy requires the Services and the Defense Logistics Agency (DLA) to "pursue the examination, evaluation, development, and implementation of CBM+–enabling technologies and process improvements." Furthermore, "CBM+ technologies and concepts will be incorporated in organic (DoD in-house) maintenance capabilities and operations as well as in commercially supported DoD systems/programs."[1]

DoD Acquisition Policy

During the initial acquisition process significantly greater emphasis is being placed on the responsibility of DoD program managers for providing sustainment support over the total life cycle. For example, program managers (PMs) are required by DoD Instruction 5000.2 to "optimize operational readiness through affordable, integrated, embedded diagnostics and prognostics, automatic identification technology; and iterative technology refreshment." This requires the PMs to take responsibility for CBM+ implementation, and translates into specific requirements that should be included in key performance parameters (KPPs) that document the implementation throughout a system's life cycle.

Additional guidance for PMs for the full range of acquisition life-cycle activities, including development of CBM+ capabilities, is contained in the Defense Acquisition Guidebook (DAG). Specific references to CBM+ in the DAG are at paragraph 5.2.1.2. This reference is available at http://akss.dau.mil/DAG. Specific guidance for development of KPPs is available in the Joint Capabilities Integration and Development System (JCIDS) Manual (CJCSM 3170.01B), Enclosure B at https://acc.dau.mil/CommunityBrowser.aspx?id=19936. Additional information regarding the implementation of CBM+ is available in "Designing and Assessing Supportability in DoD Weapon Systems: A Guide to Increased Reliability and Reduced Logistics Footprint" (October 2003). This guide describes CBM+ as an element of the PM's responsibility to achieve the objectives of increased reliability and reduced logistics footprint over the support life cycle.

DoD Maintenance Policy Directive

DoD maintenance policy (DoD Directive 4151.18, "Maintenance of Military Materiel") requires minimizing requirements for support equipment, including test, measurement, and diagnostic equipment. Maintenance programs for military materiel must utilize diagnostics, prognostics, and health management techniques in embedded and off-equipment applications when feasible and cost effective. Maintenance programs must provide the organic maintenance workforce with the range of technological tools necessary to enhance capabilities (e.g., interactive technical manuals, portable maintenance aids, access to technical information, and serial item management), to properly equip the workforce, and to provide adequate technical and managerial training.

New DoD Policy Issuance

DoD is in the process of publishing a formal policy for institutionalizing the CBM+ strategy as an element of the CPI initiative. Under DoD Instruction 4151.22 policy, CBM+ is a strategy to apply and integrate appropriate processes, technologies, and knowledge-based capabilities to increase operational availability and reduce total life-cycle costs by improving maintenance effectiveness

[1] Deputy Under Secretary of Defense (Logistics and Materiel Readiness), Memorandum for the Secretaries of the Military Departments, "Condition Based Maintenance Plus," November 25, 2002.

and responsiveness. CBM^+ is based on performing maintenance only when there is evidence of need obtained from real-time assessments, embedded sensors, or external measurements. CBM^+ uses a system engineering approach to collect data and feed the decision-making process for operations and weapon system acquisition and sustainment.

DoD activities should establish a CBM^+ environment for the maintenance and support of weapon systems by establishing appropriate processes, procedures, technological capabilities, information systems, and logistics concepts. For example, this environment will include the following:

- System health monitoring using applicable and effective embedded sensors, on- and off-system decision-support systems, and analysis tools
- Condition-driven maintenance actions at the maintainer level directed by decision-support capabilities based on timely and accurate information flow
- Reliability analysis, such as RCM
- Statistical analysis
- Automatic entry and retrieval of highly accurate maintenance data
- Integrated maintenance and logistics/supply chain, configuration management, and financial information systems
- Configuration management and asset visibility
- In-service history-based maintenance planning, equipment scheduling, and life usage tracking (trend analysis)
- Remote diagnostics, subject matter experts, and mentorship arrangements
- Low ambiguity fault detection, isolation, and prediction
- Interactive electronic technical manuals (IETMs)
- Open architecture, data-based interactive training, and technical assistance capability
- Widespread use of electronic portable or point-of-maintenance aids
- Information feedback among field personnel, weapon system and combat support developers, and materiel support developers.

Military Service Policies

To find current policy, please refer to the individual Service website or the OSD CBM+ website.

Army

Assistant Secretary of the Army (ALT) Memorandum, "Condition Based Maintenance Plus - CBM+", 20 March 2008

Army Regulation 750-01, "Army Materiel Maintenance Policy," 20 September 2007

Navy

Chief of Naval Operations (OPNAV) Instruction 4790.16, "Condition Based Maintenance (CBM) Policy," 17 December 2007

Assistant Secretary of the Navy (Research, Development & Acquisition) Memorandum, "Condition Based Maintenance Plus Policy," January 27, 2003

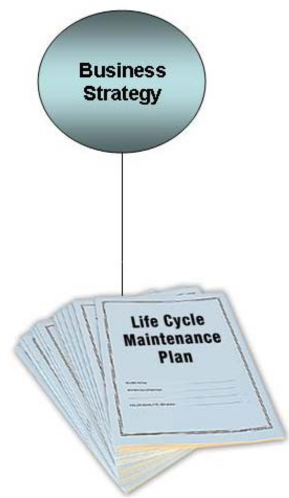
Air Force

Air Force Instruction 63-107, "Integrated Product Support Planning and Assessment," November 2004

Marine Corps

Commandant of the Marine Corps, Headquarters Marine Corps Order 4000.57, "Marine Corps Total Life Cycle Management," September 2005.

2. Business Strategy



The implementation of the CBM+ strategy in DoD maintenance organizations should not be construed as primarily the application of new methods and technologies. The basis for CBM+ is more precisely a focus on improving the business process of maintenance with the principal objective being improved operational performance as a result of increased maintenance effectiveness in terms of greater productivity, shorter maintenance cycles, increased quality of the process, and better use of resources. As noted previously, DoD Instruction 5000.2 requires PMs to optimize operational readiness through affordable, integrated, embedded diagnostics and prognostics, and embedded training and testing; serialized item management; automatic identification technology (AIT); and iterative technology refreshment.[2] In support of this requirement the TLCSM[3] concept should be used as a vehicle for ensuring the elements of CBM+ are fully considered as early as possible in the acquisition life cycle of a

[2] DoD Instruction 5000.2, *Operation of the DoD Acquisition Process*, May 12, 2003.

[3] Office of the Secretary of Defense, *DoD Template for Application of TLCSM*, August 2004.

weapon system or equipment. CBM$^+$ should be viewed as an element of TLCSM, emphasizing an early focus on sustainment within the system life cycle and part of a comprehensive view of all logistics activities associated with the fielding, sustainment, and disposal of a DoD weapon system or equipment across its life cycle.

CBM$^+$ as Part of the TLCSM Concept

Life-cycle logistics managers should incorporate the elements of CBM$^+$ in their planning efforts, beginning as early as possible in the acquisition process. The following are examples of insertion of CBM$^+$ considerations under TLCSM at life-cycle milestones:

- Including CBM$^+$ requirements as part of the overall systems engineering strategy
- Describing CBM$^+$ initiatives in the Product Support Plan documented in the Acquisition Strategy
- Describing CBM$^+$ logistics metrics, criteria, and funding requirements in the Acquisition Program Baseline
- Including CBM$^+$ logistics considerations and test points in the Test and Evaluation Master Plan and continuing testing during the life cycle to leverage future emerging CBM$^+$ capabilities
- Including CBM$^+$ initiatives in acquisition documentation such as the Initial Capabilities Document and the Capabilities Production Document
- Incorporating the CBM$^+$ strategy in PBL agreements
- Including CBM$^+$ requirements in production and sustainment program funding
- Assessing CBM$^+$ progress in Pre- and Post-Initial Operational Capability Reviews.
- Including CBM$^+$ performance factor in design reviews
- Including CBM$^+$ evaluation factors in source selection evaluation of new acquisitions.

TLCSM is discussed further in Sections 5 and 6.

CBM$^+$ Business Needs

A principal objective of the CBM$^+$ strategy is to optimize the operational availability of DoD weapon systems and equipment. This requires a more effective matching of maintenance capabilities to dynamic mission needs. Attaining the CBM$^+$ objective means a transition from a corrective or even a time-based maintenance approach to a proactive, predictive-based philosophy. This will require some significant changes in the procedural and systemic business rules regarding the amount and timing of maintenance actions in the future. To achieve this objective, maintenance managers must recognize a new business paradigm and select maintenance actions based on different and, in some cases, more challenging criteria. The criteria associated with a condition-based approach to maintenance differ significantly from past business rules. Each Service must determine its own specific maintenance business strategies based on operational need, mix of facilities, application of technologies, and availability of skills, organizational structure and resources.

Validated CBM$^+$ business strategies and related business needs must be resourced through each Service's Planning, Programming and Budget System (PPBS). This requires both a marketing effort to obtain stakeholder support and continuing oversight to shepherd the CBM$^+$ requirement through the resources management process.

Recognizing several fundamental business needs will assist in guiding the transition to a CBM$^+$-oriented business environment. The business needs outlined below provide the foundation for the development of CBM$^+$ organization-specific business rules:

1. Need to predict equipment failures
2. Need for a holistic view of equipment condition
3. Need for greater accuracy in failure prediction
4. Need to reduce the cost of ownership
5. Need to improve equipment and component reliability
6. Need to reduce equipment mean down time (logistics responsiveness)
7. Need to optimize equipment performance (availability)

These rules should be developed by implementing activities to accommodate the overarching business needs. The following paragraphs provide further elaboration.

Business Need 1—Need to predict equipment failures

Different maintenance approaches are focused on different objectives. When in the reactive mode, the motivator for improvement is the need to respond quickly to equipment and component failures. In terms of today's condition monitoring, this means the ability to find, assess, and fix failures as quickly as possible to return the end item to service. In the future, however, the primary use of condition monitoring will be to predict (and therefore assist in avoiding) unplanned equipment failures. Reliability analysis principles have taught us that a primary aspect of a predictive condition monitoring task is determining the lead time from detecting and assessing of a condition to the point of failure. Unfortunately, in practice the ability to detect and assess this deterioration for sophisticated equipment and components is highly variable. No existing condition monitoring method can give anything but an approximation of the point of failure. Application of CBM$^+$ attempts to improve the accuracy and efficiency of failure detection assessment and reaction to the prediction of a future fault or failure. Improving the ability to predict failures not only improves maintenance planning but the benefits carry over into related areas, such as supply support, use of facilities and test equipment, skills management, and other logistics support elements, and ultimately improves warfighter support, including the ability to convey platform health management status to commanders and staffs for resource planning, force planning, and situational assessments. Business rules should require maximum use of predictive maintenance strategies and implementation of CBM^+ enablers to improve failure prediction capabilities.

Business Need 2—Need for a holistic view of equipment condition

Opportunities should be identified to minimize total equipment downtime by taking a holistic view of equipment condition and combining planned maintenance tasks, whenever possible, into a single equipment availability. For example, if vibration analysis indicates a bearing failure on a particular pump was imminent, it would be preferable to assess the condition of all the other components of the pump (such as impeller, seals, and back plate) to determine whether any of these items should be replaced or refurbished at the same time as the bearings based on limited remaining life or overall cost effectiveness of maintenance efforts. Further, parts support requirements can be consolidated or time-phased if a range of maintenance actions are undertaken after the condition assessment is performed. A holistic view of equipment condition monitoring requires the integration of

- automated condition monitoring inspection results (covering all condition monitoring techniques used, such as vibration analysis, oil analysis, and thermography);
- visual inspection results;
- fixed-interval “preventive” maintenance actions;
- opportunistic maintenance; and
- equipment performance monitoring.

This integration is made more difficult because the data in each of these areas traditionally has been kept in different information systems. Implementation of the CBM^+ data warehouse concept (see discussion on page 3-20) may help alleviate this issue. Business rules should require use of the full range of monitoring capabilities to ensure full accuracy and timeliness of condition monitoring results.

Business Need 3—Need for greater accuracy in failure prediction

Even if a completely holistic approach to equipment condition is not taken, there are still significant benefits from integrating process operating data with condition monitoring analysis. The need is to incorporate operational environment and mission factors into customized failure predictions for individual systems. For example, certain electric motors will display higher vibration when operating under low loads than when they are operating under high loads. Yet in the traditional methods of vibration analysis, and using periodically collected data from a hand-held data collector, these variations are not effectively taken into account, except perhaps in a qualitative manner. If quantitative data can be collected regarding the “process conditions” that existed at the time the vibration data was collected, and correct the vibration data for these conditions, then the diagnostic capability would become far more accurate and sensitive. The sophistication of maintenance models has increased with the growth in the complexity of modern systems, which in turn has increased the complexity and capability of the analysis and solution generation procedures. This means that as the ability improves to collect and store greater amounts of more accurate condition data, the analytical software algorithms can deliver increasingly more accurate predictions of failure and related information.

To achieve greater integration, CBM$^+$ suggests tying together various data sources, or at the very least, interfacing data sources and analytical systems using common standard protocols. Modern CBM$^+$ analytic software should offer integrated condition monitoring and analysis capability, which permits the effective integration of different forms of analysis and other condition data into combined management information reports. Statistical analysis tools and CPI should be considered.

Moore's Law[4] applies here. The good news is that the costs of increased "on-system" signal processing power are decreasing dramatically. When fully implemented, smart sensor technology will greatly reduce the complexity of linking the outputs of these sensors to process control and analysis systems. More and more equipment will be able to be monitored continuously, on-line, and operators will be able to assess, quickly and easily, the current, and perhaps the future, condition of components of particular equipment. Business rules should require prudent investment in sensor, data collection, and analytic capabilities to minimize condition monitoring and failure analysis errors.

Business Need 4—Need to reduce the cost of ownership

For CBM$^+$ to be successful, the algorithms that are used both on and off systems to process condition data must be accurate, reliable, and cost effective in assessing equipment condition and predicting equipment failure. In the early days of sensor analysis, accurate diagnosis of equipment failure was largely dependent on the skill and experience of individual human analysts. However, with the development of more effective analysis software, the full reliance on a highly skilled analyst has been reduced. While individual skill is still important—particularly for more complex analysis—the capability of analysis software to generate trends, as well as various forms of user-set alarm levels, has made the "first-pass" assessment of failure problem easier which offers the potential to reduce the cost of ownership.

Some vendors also offer so-called "expert" systems for fault diagnosis. At present, these expert systems are still essentially rule-based systems, and like all rule-based systems, the results are only as good as the rules that have been established within the system. Nevertheless, if smart sensor technology is to work, and if widespread on-line condition monitoring is to proliferate, the development and application of better and more accurate "expert" software is essential.

The impact of these improvements in failure diagnosis software will be two-fold. First it will improve the consistency and accuracy of failure diagnosis. Second, it will reduce the labor required to assess equipment condition. Some organizations already use fairly rudimentary "first-pass" vibration or oil analyses that are conducted by equipment operators to determine whether a particular item of

[4] The observation made in 1965 by Gordon Moore, co-founder of Intel, that the number of transistors per square inch on integrated circuits had doubled every year since the integrated circuit was invented. Moore predicted that this trend would continue for the foreseeable future.

equipment has a problem. Only after a problem is identified, does the condition-monitoring technician become involved in conducting a more detailed analysis and diagnosis.

With the advent of more sophisticated condition assessment software and more efficient storage and communications capabilities, the costs of CBM$^+$ relative to benefits should decrease. This is particularly true when the broader implications of CBM$^+$ cost-reduction opportunities are considered. For example, accurate failure prediction would streamline supply chain operations by reducing administrative downtime associated with acquiring spares and repair parts. CBM$^+$ will support “root cause” analyses to identify the underlying causes of equipment failure and assist in designing “fixes” to significantly reduce or eliminate related failures. Business rules should require development of a reasonable business case and application of the results of such analyses to ensure the most efficient return on investment from a CBM$^+$ initiative.

Business Need 5—Need to achieve inherent equipment reliability and to improve equipment and component reliability

Once an effective condition-based set of maintenance tasks has been established within an organization, several opportunities for improvement exist:

- Progressive monitoring and reduction of repeat inspection intervals for maintenance tasks, based on actual equipment performance.
- Examination of “shop findings” from equipment repair tasks to adjust maintenance standards and tolerances or by improving the precision (frequency and quality) with which maintenance is performed, thereby taking advantage of the equipment or component’s inherent level of reliability.
- Identification of opportunities for equipment modification or component replacement with more reliable items or with redundant capabilities that will significantly improve operating reliability, maintainability, and supportability.

CBM$^+$ can enhance these opportunities in a number of ways, including designing in sensor capabilities, built-in-test and built-in-self-test mechanisms to support identification of failure patterns, rigorous condition assessments, and provision of performance data that can assist in justifying investments in equipment or component reliability.

Traditionally, condition analysis has consisted of assessing the causes of failure and then comparing these with some (usually fairly arbitrarily determined) warning or alarm levels, above which some preventive or corrective action is required. Because there is a strong correlation between out-of-tolerance condition and equipment or component life, a more rigorous method of determining condition alarm levels will help decision makers trade-off investment in increased reliability and investment in additional maintenance. This assessment will require consideration of such factors as

- criteria for changes to design and capability;
- the consequences of failure (in terms of increased costs, lost productivity, safety or environmental impact);

- the cost trade-off between more frequent, and more rigorous condition monitoring, and improved component or equipment design to increase reliability; and

- underlying maintenance and operating conditions

By applying CBM$^+$ to implement an additional level of sophistication above what is currently applied by condition-monitoring practitioners, decisions regarding improving reliability or revising maintenance approaches will facilitate a more effective equipment management process. Business rules should require full availability and consideration of condition-monitoring analysis information as part of the justification to significantly invest in reliability improvements or to make major changes in equipment maintenance approaches.

Business Need 6—Need to reduce system mean down time (logistics responsiveness)

The increased efficiency of the maintenance process attainable through implementation of CBM$^+$ should be evidenced by significant reduction in overall mean down times for those systems and components where CBM$^+$ capabilities are introduced. DoD policy defines mean down time as "the average time a system is unavailable for use due to either corrective or preventive maintenance; time includes actual repair time and all delay times."[5] Application of the mean down time metric to assess the impact of the CBM$^+$ initiative is particularly appropriate because this metric establishes a direct relationship between the selection of alternative maintenance strategies and the attainment of desired levels of logistics responsiveness. To the extent the introduction of CBM$^+$ improves responsiveness, overall maintenance costs are optimized and systems availability is increased. Meeting these business needs ultimately results in greater customer satisfaction. Specific business rules should be developed to track the reduction of system and component mean down time.

Business Need 7—Need to optimize equipment performance (availability)

Improved condition monitoring goes hand-in-hand with improved performance management. In many instances the same factors measured in determining equipment and component condition are also assessed in determining the levels of performance (e.g., speed, operating times, endurance, and lift capability) that can be attained by a given weapon system or equipment. For example, steam turbines measure performance based on temperature, pressure, power output, and others. These are some of the same measures used to determine turbine condition and the specific faults that may require attention. This type of monitoring is becoming more widespread on large equipment like DoD weapon systems. As automated condition monitoring is made more cost-effective through CBM$^+$, the interaction between condition analysis and operational performance (i.e., system availability) will become more obvious to both operators and maintainers. Improved condition-monitoring capabilities may also impact equipment design by reducing the need for some component redundancies.

Exploiting the relationship of the CBM$^+$ strategy implementation to assess both logistics responsiveness and system availability (Business Needs 6 and 7) becomes another key element of the

[5] USD(AT&L) Memorandum, "Total Life Cycle System Management Metrics," November 22, 2005.

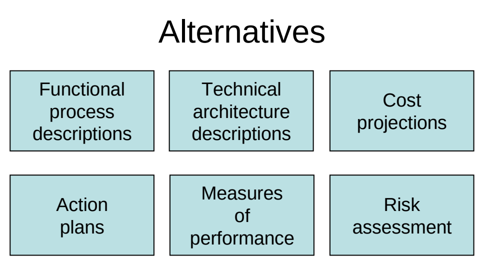
CBM$^+$ business strategy. Business rules should require development and use of metrics driven by condition-based information as part of the responsiveness and performance components of a balanced assessment program.

Making a CBM$^+$ Business Case

The business needs outlined above will help maintainers formulate business rules for day-to-day application of CBM$^+$ capabilities; however, they still need to recognize that implementing new processes, practices, and technologies also brings an inherent requirement for additional resources. CBM$^+$ initiatives must be cost-effective because it is conceivable that a particular application or supporting process could be more expensive to install than the projected benefits for the application. Therefore, CBM$^+$ implementation requires a management decision to invest in the elements that are needed to facilitate the transition to a predictive, condition-based environment as described in this Guidebook. The decision-maker needs timely, consistent, complete, and accurate information. The business case facilitates decisions that are consistent with the organization's goals and mission objectives. It provides a formal yet flexible system to manage individual initiatives more efficiently and align them with other competing resource requirements. The business case analysis is useful whether deciding to invest in CBM$^+$ practices or technologies for a given weapon system or equipment, or deciding, through reliability analysis, to apply a CBM approach or some other maintenance strategy.

A decision to move ahead with CBM$^+$ should rest, at least in part, on preparation of a credible business case analysis (BCA). While the idea of creating a business case sounds ominous, the basic concept of such analysis is relatively straightforward. A business case in its simplest form is a verifiable statement—regarding an alternative capability or action—of whether the long-term return on the investment is greater than the cost of implementation. This comparative analysis is generally expressed in the form of a description of several alternatives to achieve the desired objectives or changes with corresponding costs and benefits. The components of alternative approaches within a basic business case are shown in Figure 3-2.

Figure 3-2. Alternatives within a Business Case Analysis

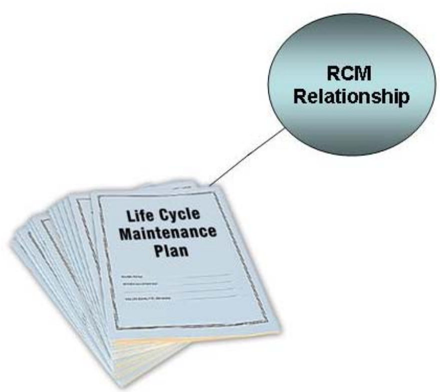


It is important to realize that return on investment and costs may not be the only or even the most important factors in a BCA. Although the business case must consider the cost of the initiatives, it must also identify the overall value to attaining the organization's mission objectives. A defensible business case, particularly in DoD, may include benefits and mission capabilities to the operator that may be as important as the resource business case in justifying implementation. A good business case states the costs of implementation, but expresses return or benefits in both tangible (dollars, personnel, and facilities) and intangible (improved performance, safety, or time saved) terms. The BPA should reflect the cost of process improvement or technology insertion over the life of the weapon system or until the system is scheduled for replacement in a modernization program, which ever is less. The decision to include or exclude a CBM+ technology should be based on a BPA. If THE technology is removed or replaced for some reason later in the acquisition process, a new BCA should be completed to reflect the change in life-cycle costs.

Regardless of where an organization is in its efforts to implement CBM+, early in the acquisition of a new weapon system or well into the sustainment phase of a weapon system or equipment, the BPA is a valuable management tool. A well-constructed business case presents management with decision-making information in a consistent framework that will allow the comparison, evaluation, and prioritization of competing and overlapping process change initiatives. Additional information on BCAs is available at https://acc.dau.mil/CommunityBrowser.aspx?id=32524&lang=en-US. One source of BCA training from the Defense Acquisition University is available at https://learn.dau.mil/html/clc/Clc1.jsp?cl=.

Once the CBM+ business case is developed, it becomes an essential tool for validating and supporting the CBM+ requirement to appropriate functional and resource managers. The results of the BPA should be incorporated into applicable requirements, programming, and budgeting justification documents.

3. RCM Relationship



There is a close relationship between CBM+ and RCM. RCM analysis helps determine the criticality of equipment failures relative to equipment availability and the importance of the equipment to accomplishing the organization's mission. RCM also provides rules for determining evidence of need for CBM. Recent advances in technology, such as sensing hardware, electromechanical interfaces, data accumulation, modeling and simulation, wireless communications, and equipment health monitoring systems, can significantly improve system safety, reliability, and affordability. When implemented effectively in an integrated fashion, these and other CBM+ capabilities can improve maintenance performance and reduce funding and personnel requirements.

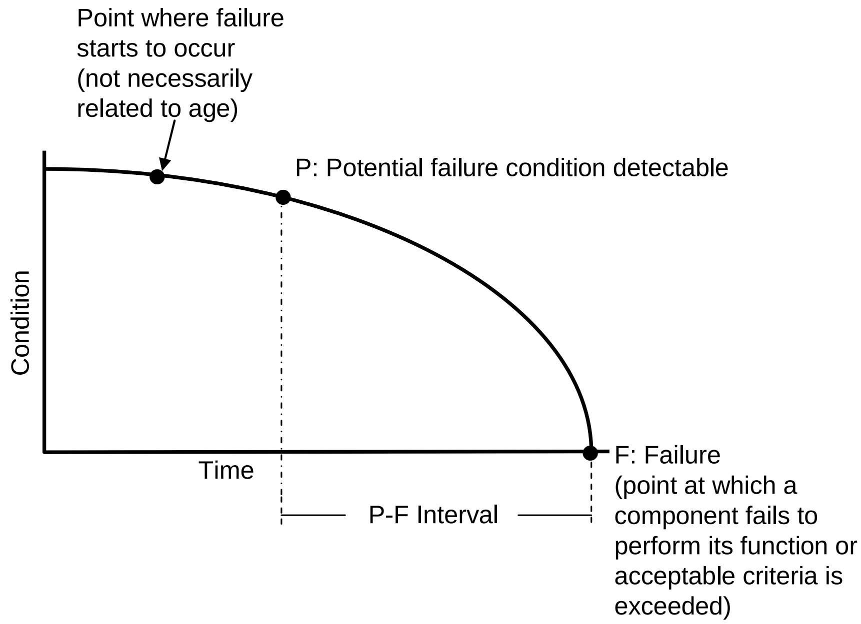
RCM is a logical, structured process for determining the optimal failure management strategies for any system, based upon system reliability characteristics and the intended operating context. RCM defines what must be done for a system to achieve the desired levels of safety, environmental soundness, and operational readiness at the best cost. Specifically, RCM identifies the concepts and methods needed to select technically appropriate maintenance actions, such as predictive and preventive tasks that will prevent failure. RCM also identifies default strategies, such as failure finding tasks, engineering redesigns, and changes to operating procedures.

"If maintenance is ensuring that physical assets continue to do what their users want them to do; then, RCM is a way to determine what must be done to ensure that any asset continues to do what its users want it to do in its present operating context."[6] For example, the Naval Air Systems Command (NAVAIR) defines RCM as "an analytical process to determine the appropriate failure management strategies to ensure safe operations and cost-wise readiness."[7] RCM analysis considers the failure process and related reliabilities of equipment, the severity of the related consequences of failures, and the cost effectiveness of various options to deal with failure.

In the context of RCM, there are essentially two types of maintenance: proactive and corrective. These have been presented using different terminology over the years. Essentially, proactive maintenance actions are taken to preserve functionality (often protecting safety or reducing the cost of repair) and reduce unplanned downtime or impacts to mission performance. It should be noted that proactive actions by their nature require some level of investment (such as to analyze, inspect, refurbish, and replace) above just the correction of the failures. The RCM process evaluates the trade-off between this investment and the overall cost. Corrective maintenance, on the other hand, responds to failures after they occur. This may be the most effective approach for many types of equipment when the consequences of failures are acceptable or unpredictable. In a "failure management strategy," RCM determines the proper balance between these planned and unplanned activities.

DoD's efforts to transition from the current reactive and time-driven strategies for equipment maintenance account for current approaches that have become both cost prohibitive and less than optimal in meeting today's operational availability needs. RCM identifies actions that, when taken, will reduce the probability of failure and are the most cost effective. One option of RCM is to choose to execute CBM actions. Once a possibility of failure is identified, it can be analyzed to determine if CBM is technically appropriate and effective. Figure 3-3 depicts what is called a classic "P-to-F" curve.

Figure 3-3. Classic P-to-F Curve



[6] John Moubray, *Reliability-Centered Maintenance II*, Industrial Press, New York, 1997, p. 7.

[7] NAVAIR Manual 00-25-403, *Guidelines for the Naval Aviation RCM Process*," July 2005.

Figure 3-3 illustrates that many types of equipment will show detectable signs of impending failure before the equipment actually fails. The point at which deterioration is first detectable is the point "P." If an inspection of some kind can discover the deterioration between the time it is first detectable and the time when functional failure occurs (point "F"), then there is an opportunity to avoid the failure. The time interval from when "P" can be detected and "F" occurs is called the P-F interval. The P-F interval governs how often a CBM task is performed and when action must be taken to correct the impending failure.

By employing CBM$^+$ capabilities, system operators and their maintenance support team are made aware of pending failures in advance, so they are able to accomplish appropriate actions to prevent the loss of use and cost related to experiencing the actual equipment failure. It is this predictive aspect of CBM$^+$ that clearly distinguishes this strategy from traditional approaches to maintenance in the DoD.

Successful, long-term reliance on the CBM strategy is greatly enhanced through implementation of CBM$^+$ initiatives for improving weapon system and equipment maintenance. If CBM$^+$ is implemented, there must be a high degree of confidence on the part of users and customers that this effort will reliably produce maximum equipment availability at a reduced cost. This means the predictive capabilities instituted under CBM$^+$ must consistently and accurately result in fewer unplanned failures, generate fewer unnecessary maintenance actions, and reduce overall costs as compared to the more traditional strategies.

As weapon systems and equipment have become more complex, the patterns of failure and the difficulty of predicting failures have also become more complex. The need to prevent or predict failures, particularly when human safety is involved, has prompted maintenance and operational managers to look for new types of failure management, particularly in the area of predictive assessment. In some cases, it is possible to identify the potential failure condition and associated P-F interval relatively easily when subject matter experts are asked the right questions. The focus on predicting rather than waiting for failure is based on the idea that many failures give some type of warning or show some detectable characteristic prior to the actual failure event. On-condition maintenance and the related term, CBM, are used to address the capability to detect or predict deterioration or failure in advance of the actual event and to take appropriate action once there is reasonable certainty that the degradation is likely to occur in a particular time frame. RCM provides a structured and easily understandable process for determining which (if any) maintenance actions should be undertaken and when such actions are technically appropriate.

The RCM analytical approach helps the maintenance manager in identifying potential failures and supporting the selection of viable courses-of-action. RCM tools help define the optimal failure management strategies and provide the inputs to construct the business case for implementation of the designated CBM$^+$ strategy. CBM$^+$ builds on the foundation of RCM, but complements and expands on RCM by applying a broad spectrum of procedures, capabilities, and tools to improve execution of the maintenance analysis process. Table 3-2 relates the RCM process steps with representative capabilities of CBM$^+$.

Table 3-2. CBM$^+$ Capabilities Relative to RCM Process Steps

RCM process steps	CBM$^+$ enabling capabilities
Functions: the desired capability of the system, how well it is to perform, and under what circumstances.	Provides analysis and decision support to help determine the life-cycle maintenance strategy to ensure achievement of required system performance. Provides technical data for a business case to determine optimal application of resources to perform selected maintenance tasks.
Functional failures: the failed state of the system. Generally speaking, when the system falls below the desired performance standards.	Provides diagnostic tools to assess degree of system/component degradation. Tracks health and status of installed components.
Failure modes: the specific condition causing a functional failure.	Uses sensor and data analysis technology to identify failure causes; collects, stores and communicates system condition and failure data.
Failure effects: the description of what happens when each failure mode occurs, detailed enough to correctly evaluate the consequences of the failure.	Uses automated tools and data manipulation software to produce diagnostic information on detected failures. Applies information from Interactive Electronic Technical Manuals to report, troubleshoot, test, and support documentation of failures.
Failure consequences: the description of how the loss of function matters (e.g., safety, environmental, mission, or economics).	Maintains platform hardware and software configuration. Provides data warehouse capability as a comprehensive database that includes condition trends, history, and transaction records from business processes. Available to the full range of users.
Maintenance tasks and intervals: the description of the applicable and effective tasks, if any, performed to predict or prevent failures.	Incorporates prognostic capabilities to help predict failure causes and timing. Embedded health management systems on each platform predict the remaining useful life of equipment/components based on failure predictors derived from composite condition analysis.
Default actions: including but not limited to failure-finding tasks, run-to-failure, engineering redesigns, and changes/additions to operating procedures or technical manuals.	Supports standard graphics and trending displays, user alerts, data mining and analysis, simulation and modeling, enterprise decision-support systems, and advisory generation.

CBM$^+$ is not a process; it is a comprehensive strategy to select, integrate, and focus a number of process improvement capabilities, thereby enabling maintenance managers and their customers to attain the desired levels of system and equipment readiness in the most cost-effective manner. As shown above, the CBM$^+$ strategy includes a number of capabilities and initiatives, some procedural and some technical, that can enhance the basic RCM tasks. In this way, CBM$^+$ enables a more effective RCM analysis.

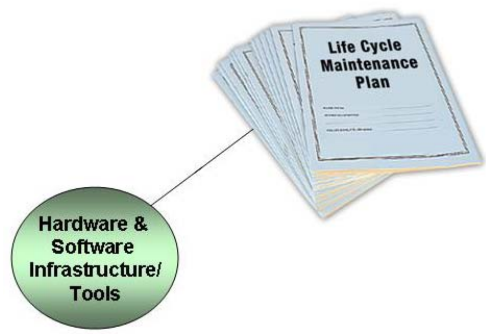
If the RCM analysis suggests revision of maintenance tasks, then the maintenance manager should accomplish an assessment of how CBM$^+$ capabilities may be applied to support the revised maintenance task procedures. Often, the revised tasks require fundamental changes to the maintenance strategy such as transition from time cycle repair intervals to CBM. In other cases, application of sensor capability or diagnostic software may be in order. If the proposed revisions are significant in terms of procedural changes or cost, a formal BCA may be necessary to justify the increased resource or time investment. CBM solutions are selected based on the frequency and impact of the failure modes; the ability to employ some form of automated status sensors or other CBM$^+$ technologies; and the expected performance, safety, or cost benefit of investing in the capability. Using CBM$^+$, maintainers can identify and respond to deteriorating equipment conditions more effectively, without having to wait for a failure. CBM$^+$ not only emphasizes a different approach, it also allows a net reduction in the amount of maintenance performed, which affects all the associated logistics elements, including parts and other footprint factors.

Clearly RCM and CBM$^+$ have a mutually beneficial relationship. From a weapon system or equipment perspective, health management without RCM analysis becomes technology insertion without a justified functionality. Conversely, collection of aggregated or platform-centric health data without an understanding of which failure modes are consequential, and which ones are not, and the most effective course-of-action, can lead to wasted effort and unnecessary expenditure of resources. For additional detailed information on RCM, information is available at https://acc.dau.mil/CommunityBrowser.aspx?id=111386.

Technical

Technical elements include the range of hardware, software, and related tools that are available for full and effective implementation of a CBM$^+$ strategy. Specific areas include hardware and software infrastructure tools, DoD architecture for CBM$^+$, and open systems and data strategy.

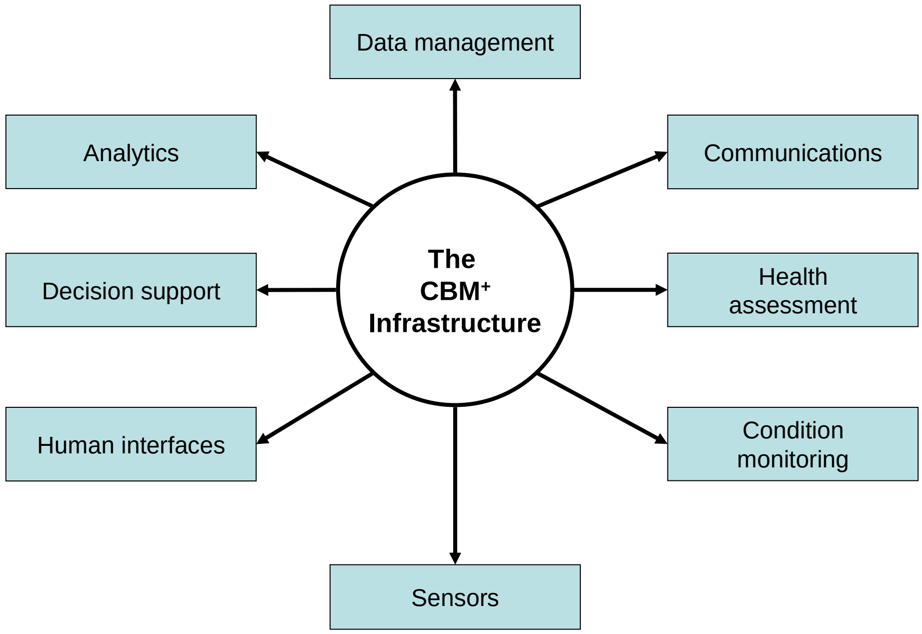
4. Hardware and Software Infrastructure and Tools



When measuring equipment condition, the ideal operational health of specific components or a complex system is determined based on inputs from sensors or a sensing system both on- and off-board. This information then is used within an infrastructure of hardware, software, and related tools to make maintenance or operational usage decisions. Accurate and reliable predictors of equipment health and the remaining useful life of equipment may be used to determine operating risk for the next operations or in setting maintenance cycles, the most efficient scheduling of maintenance actions or inspections, or indicating usage modifications to delay failure or repair. Achieving the full benefit of CBM$^+$ requires putting in place an integrated CBM$^+$ infrastructure. This infrastructure consists of a number of hardware and software elements that work together to provide the capabilities inherent in the CBM$^+$ strategy. Typically, CBM$^+$ implementers will utilize a variety of commercial off-the-shelf (COTS) hardware and software products (using a combination of proprietary and open standards). In practice, a CBM$^+$ implementation will consist of hybrid approaches including fragmented approaches (individual components implementing individual functions) and integrated approaches (individual components integrated across CBM$^+$ functions).

The infrastructure for CBM$^+$ is divided into the eight main areas shown in Figure 3-4. The infrastructure construct is often described in other ways such as on-platform and off-platform or as different hardware and software components. However, this Guidebook presents the eight areas as a comprehensive depiction of total infrastructure framework of a CBM$^+$-focused environment.

Figure 3-4. CBM^{+} Infrastructure Areas



Proponents of CBM^{+} should consider all eight infrastructure areas as the building blocks of an overall implementation strategy. Each area complements and supports other parts of the overall CBM^{+} strategy and each provides an indispensable contribution to a total CBM^{+} capability.

Sensors

Sensors are physical devices that monitor, record, or transmit equipment or component operating parameters or conditions. They can be permanently embedded on equipment, temporarily connected to equipment, or electronically connected in a wired or wireless mode. Sensors may range from relatively simple single-function units to multipurpose testing equipment with embedded analytic capability. Sensors are often positioned on or near the equipment being monitored.

Condition Monitoring

Condition monitoring is a maintenance process in which the condition of equipment with regard to physical characteristics is monitored for signs of impending failure. Equipment can be monitored using sophisticated instrumentation, such as vibration analysis equipment, or using the human senses. When instrumentation is used, parameters can be imposed to trigger maintenance response. Condition monitoring converts an output from the sensor to a digital parameter representing a quantifiable physical condition and related information (such as the time calibration, data quality, data collector utilized, or sensor configuration). Condition monitoring provides the link between the sensor device and the health assessment analysis capability. Condition monitoring includes such technologies as

- vibration measurement and analysis,
- infrared thermography,

- oil analysis and tribology (friction/wear analysis),
- ultrasonics, and
- motor current analysis.

Health Assessment

Health assessment is the capability to use the inputs from condition monitoring of system behavior (machine condition) and to provide to the operator and support management an assessment of the equipment's operational condition (i.e., assessment based upon current measurements and related data).

Health assessments based on condition monitoring are accomplished on the platform or operating equipment in real-time. An "on-system" health assessment includes sensor signal analysis, produces meaningful condition descriptors, and derives useable data from the raw sensor measurements (i.e., model-based reasoning combined with on-system real-time analysis of correlated sensor outputs). Health assessment facilitates the creation and maintenance of normal baseline "profiles" and identifies abnormalities when new data are acquired, and determines in which assessment category, if any, the data belong (e.g., "alert" or "alarm"). Health assessment software diagnoses component faults and rates the current health of the equipment or process, considering such inputs as sensor output information, technical specifications, configuration data, operating history, and historical condition data. At the operational or tactical level, on-system heath assessment helps operational commanders gauge the operating capabilities of weapons and equipment under their control. It also assists in maintenance decision making regarding appropriate repair actions and future equipment availability.

Equipment health assessment may also be conducted in proximity to the system—"at-system" assessments using a portable maintenance aid (PMA) that interfaces to the equipment indirectly through an equipment access panel or directly to line replaceable units. The PMA is then used to update "off-system" databases for real-time or future health assessment. At systems information from inspections and non-destructive evaluations (NDE) are also important sources of equipment health assessments.

The long-term health assessment goal is to provide managers with predictions about the remaining useful life of the machine before maintenance is required. There are two fundamental aspects to employing CBM$^+$ health assessment capabilities. The first relates to on-system processing and predictive maintenance (to the extent a platform is enabled with those capabilities). Generally, on-system assessment data processing is automated, and analysis is performed through the use of embedded processors. The second aspect of health assessment is the off-system processing of collected sensor data from data storage and management. Off-system analysis uses communications networks, databases, and health analysis software applications that make up the enterprise-level capability for CBM$^+$ data collection and analysis. Off-system processing is discussed below under Analytics.

Communications

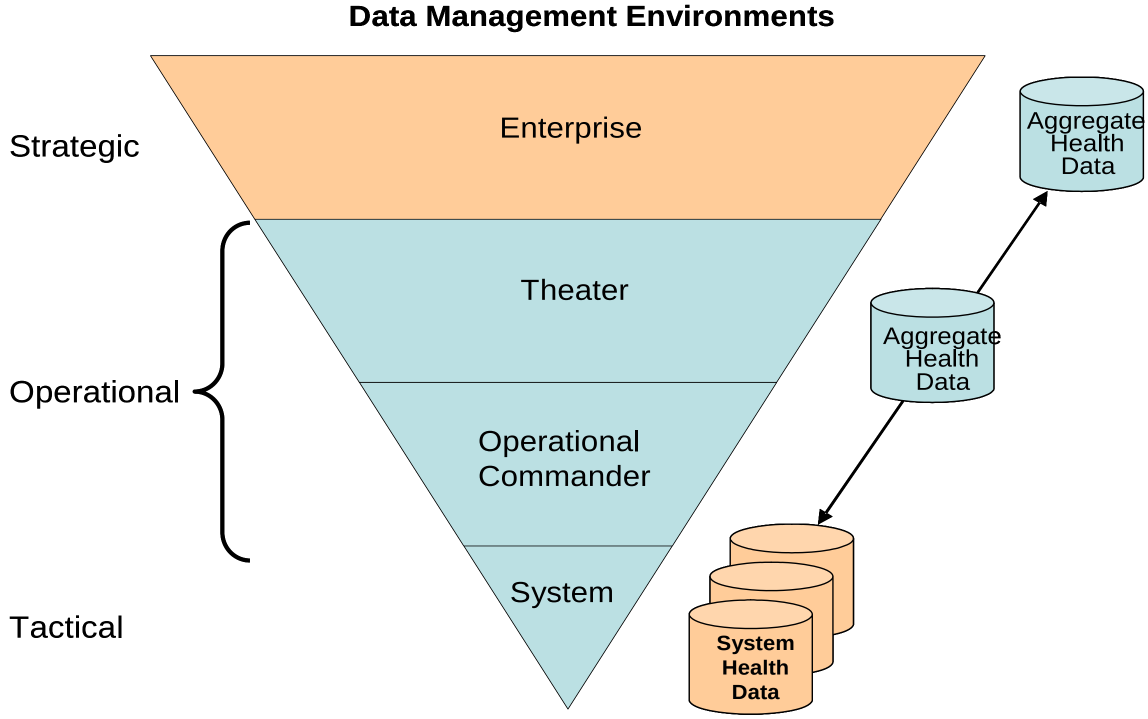
Communication of condition-related data, other technical information (such as configuration data), technical descriptive data, maintenance procedures, and management information is critical to an effective CBM$^+$ implementation. The sharing of maintenance information and other data among all elements of a CBM$^+$ environment should be possible, regardless of the data storage location. An open architecture, commercial, or DoD-recognized data standard should be used to facilitate the sharing of data outside a single system and to provide for future updates and upgrades. On-system data should be accessible to other on-system components using hardware data buses or collocated data repositories. Similarly, at- and off-system applications may require connectivity to required data sources using database access or interchange of transactions. Digital logbooks, message management software, and database management software should be implemented to ensure needed communications capabilities. As the CBM$^+$ environment becomes more complex and extensive, the expanded use of multiple communications mechanisms will occur. The CBM$^+$ implementer should plan for the maximum application of data communications standards (as described earlier) to facilitate the various data exchange requirements. Examples of some available technical approaches are described in Section 2 of this Guidebook and the CBM$^+$ website.

Data Management

Data management is central to implementation of CBM$^+$. Data management consists of acquiring data (e.g., through sensors or other acquisition techniques), manipulating data into meaningful form (e.g., converting analog to digital data), storing data (electronically in digital form), transmitting data (through electronic means), accessing data as a basis for analysis, and providing data (information) to decision makers.

In support of CBM$^+$, data are held in two ways: on-system in small amounts to support embedded health assessment and reporting, or off-system in a larger electronic storage media sometimes referred to as a data warehouse. A data warehouse is a computer database that collects, integrates, and stores an organization's computer data with the aim of maintaining and providing accurate and timely management information and supporting data analysis. The data may be distributed; that is, located at multiple organizational and locations. One issue relating to the CBM$^+$ database concerns data access and sharing. For example, if the CBM$^+$ database comprises the single physical repository for condition, performance, trending history, and other data categories, then each database user including government and contract activities will require access to pertinent portions of the database. Any effective CBM$^+$ database should have well-established procedures for granting access to qualified users, and should apply available data format standards and definitions to ensure viable information exchange and a consistent data product for each using function. Collection and aggregation of CBM$^+$ data is a common concept and a good model for the composite or "virtual" database structure. Figure 3-5 shows a notional database with a hierarchical structure representing multiple segments of the total CBM$^+$ data environment. CBM$^+$ implementers may tailor this structure based on organizational or process requirements and the availability of an effective communications capability.

Figure 3-5. CBM+ Notional Data Environment



Analytics

Analytical software is one of the most essential parts of a CBM+ strategy. For this Guidebook, analytics is defined as the off-system aspect of condition-based health assessment. Depending on the architectural approach used for CBM+ implementation, the analytic capability will need to acquire data from all sources within the architecture using different techniques, such as data mining.

The primary function of the analytic element is to determine the current health state of equipment and project this assessment into the future, taking into account estimates of future usage profiles. Root-cause analysis and tailored analytic algorithms may support this function.

Health management analysis software, which is available commercially, can identify a system or component that is affecting availability. It comes in many forms:

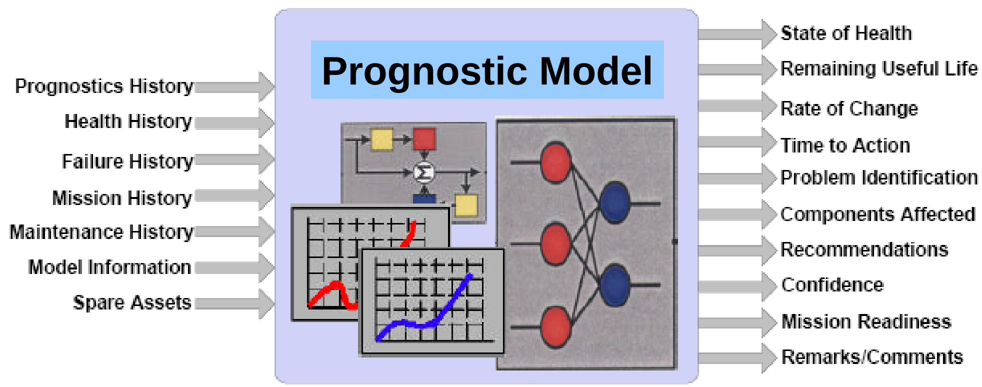
- The most basic form is condition monitoring using single-sensor monitoring with specified signal outputs used to identify condition thresholds for alarms and alerts.
- Diagnostic assessment identifies fault conditions and compares the current health of the equipment or process against “normal” parameters, considering available historic or technical information.
- Predictive assessment predicts future health states by extrapolation and correlation of archived sensor data.

- Trend analysis is a form of predictive assessment derived from data obtained from equipment sensors that primarily perform operational or diagnostic measurements. Trend analysis will not precisely forecast remaining equipment life, but it can signify a problem when added knowledge of equipment performance requirements identifies the upper and lower boundaries of component failure rates.

- Prognostic assessment is the ability to perform a reliable and sufficiently accurate prediction of the remaining useful life of equipment. This allows the conditioning monitoring system to do more than just react to threshold crossings and diagnostic alerts.

Depending on the organization's requirement for CBM+ capabilities, data collection and health management analysis may be used for a range of purposes, from a simple condition assessment for a single component to a full condition assessment with projections of useful life expectancies across a fleet of equipment. Figure 3-6 shows generic possible inputs and output results from a reasonably comprehensive prognostic software model.

Figure 3-6. Generalized Inputs and Outputs from a Prognostic Model



Source: Lebold, Mitchell and Michael Thurston, "Open Standards for Condition Based Maintenance and Prognostic Systems," Applied Research Laboratory, Penn State University, May 2002, p. 9.

A prognostic module must be flexible enough to accept many different sources of information to adequately and accurately predict the remaining useful life. By predicting the remaining useful life, the prognostic capability assists the operators and managers in actively managing their maintenance resources and determining appropriate maintenance actions. Effective use of prognostic assessment or "prognostics" can be the ultimate goal of predictive maintenance.

Decision Support

Regardless of its sophistication, a complete CBM+ capability includes the ability to make maintenance and related support decisions based upon the available condition data. This involves using decision-support software to assess equipment operating reliability and availability, identify needed changes in planned maintenance requirements and equipment modifications, and track equipment operating performance (for individual components, equipment or groupings of equipment.) The objective is to predict problems or failures in time to take remedial action. Decision support includes analytic and decision-support tools to help managers at all levels identify adverse trends and assist in maintenance planning. It may also include the use of data by other sustainment providers in such areas as supply, transportation, or engineering to ensure required support is available where and when it is needed by the operating forces.

The decision-support capability acquires data from the diagnostic and prognostics analytic elements. The primary function of decision support is to recommend maintenance or engineering actions and alternatives and to understand the implications of each recommended action. Recommendations include establishing maintenance action schedules, modifying the operational configuration of equipment to accomplish mission objectives, or modifying mission profiles to allow mission completion. The decision logic needs to take into account such factors as operational history (including usage and maintenance), current and future mission profiles, high-level unit objectives, and resource constraints. An accurate forecast of an asset's future use needs to match the other systems planning horizon to be effective. Output from the decision-support capability should be in the form of automated notices, computer-to-computer transactions, alerts and alarms, or other advisory generations, including health and prognostic assessments.

Human Interfaces

The human interface layer may access data from any of the other layers within the architecture, such as the decision-support component. Typically, status or recommendations (health assessments, prognostic assessments, or decision recommendations) and alerts would be produced and displayed to human users by the decision software, with the ability to drill down when anomalies are reported or additional information is required. Humans also can input condition information, such as from inspections or NDE, to affect maintenance decisions. In many cases, the human interface capability will have multiple layers of access to data across the CBM+ environment, depending on the information needs of the user. This capability may also be implemented as an integrated multiple-user interface that accounts for the information needs of users other than maintainers. The goal of the human interface is to provide operators with actionable information regarding maintenance or operations that suggest or support management or technical decisions.

5. DoD Architecture for CBM+

An architecture is the fundamental organization of a system or process embodied in its components, their relationships to each other and to the environment, and the principles guiding its design and evolution. The Department of Defense Architectural Framework (DoDAF) defines a common approach for architecture description development, presentation, and integration for both DoD's warfighting operations and for business operations and processes. The framework is intended to ensure design descriptions and interfaces can be compared and related throughout the product or process life cycle across organizational and functional boundaries, including Joint and multinational boundaries. A full discussion of DoD AF is available at http://www.defenselink.mil/cio-nii/docs/DoDAF_Volume_I.pdf.

CBM$^+$ concepts, policies, procedures, practices, systems, and technologies require integration, connectivity, and a common purpose across functional, organizational, and physical boundaries. The complexity and diversity of the components of CBM$^+$ mandate a structured plan to ensure complete and effective implementation of all required elements in a reasonable timeframe. Therefore, it is imperative that individuals and organizations charged with implementing CBM$^+$ and overseeing such an effort have a comprehensive and understandable picture of their strategy. Services and programs are provided the flexibility to develop and design CBM$^+$ related architecture. For CBM$^+$, an architectural representation can provide a holistic view and a mechanism for enabling the execution of the design and development as well as for communicating the initiative goals to managers, customers, and stakeholders.

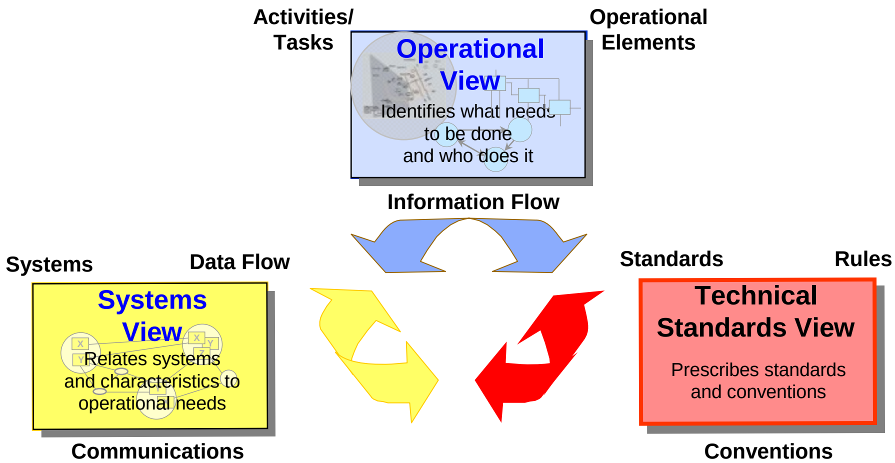
Development of an integrated CBM$^+$ architecture early in the implementation process is useful for several reasons:

- Validating the need for the several components of the overall CBM$^+$ design.
- Identifying capability gaps in the initiative design.
- Showing the elements and connectivity of system-generated information to the off-system logistics and operational systems, thereby establishing the basis for information exchange and health assessment capabilities.
- Identifying redundancies or unneeded elements of the overall design.
- Determining the positioning of data collectors, information processing capabilities, and analysis processors at strategic locations in the CBM$^+$ architecture.
- Identifying information exchange pathways and storage nodes.
- Ensuring interoperability and compatibility of process and system components across the scope of the initiative.
- Documenting human interface requirements and locations.
- Synchronizing the timing and resource expenditure for implementing the various CBM$^+$ elements.
- Supporting resource requirements to accomplish implementation.

From a program management point of view, a comprehensive and credible architecture can be invaluable in supporting the CBM$^+$ strategy during reviews that occur throughout the system's life cycle as part of the Joint Capabilities Integration and Development System (JCIDS) requirements generation; DoD planning, programming, budgeting, and execution process; and Defense Acquisition System process.

Full development of an integrated architecture requires the preparation of three types of DoDAF architecture views: operational (OV), systems (SV), and technical standards (TV) views, as shown in Figure 3-7.

Figure 3-7. DoDAF Architecture Product Relationships



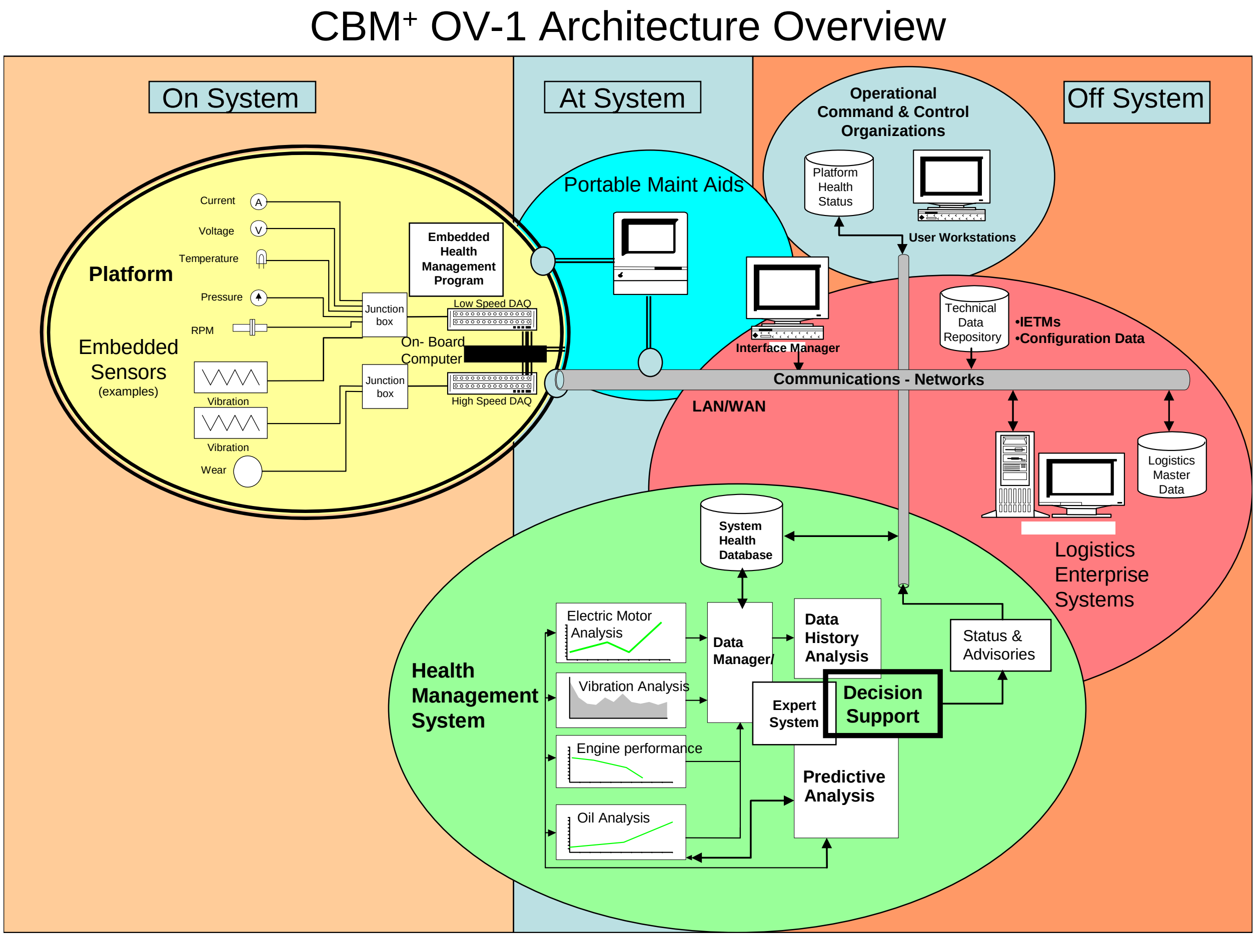
By developing these architectural products early in CBM+ implementation, maintenance managers will have a significantly greater understanding of the component elements of the CBM+ initiative from a functional and technical perspective. They also will fully understand the cause-and-effect and dependency relationships among operational tasks, supporting systems, and the technical standards used to construct the overall CBM+ environment. This means, before hardware and software technologies are acquired at considerable expense, the CBM+ manager will have worked out the proper application and level of effectiveness of proposed technology enablers and understand just how these technology tools will work to satisfy functional requirements and improve performance against operational objectives. Equally important, the CBM+ implementer may use the architectural products to clearly explain the systems, technology, and operational relationships to both stakeholders and operational customers.

By both DoD mandate and good engineering practice, the DoDAF construct is based on industry open-architecture specifications and widely accepted data models. CBM+ implementers should make use of the DoDAF conventions to effectively describe the full scope of the CBM+ initiative. The complete set of DoDAF products includes 26 different views that document the entire architecture, from requirements to implementation. For practical purposes, however, organizations charged with CBM+ implementation may wish to develop a basic set of documents that convey the essential aspects of their CBM+ strategy. In general, they could include the following views:

- OV-1, the Operational Concept Graphic, is a general picture that describes the problem that the architecture addresses. This graphic is formatted as a high level structured cartoon. It orients the reader to the problem. Figure 3-8 is an example of one approach to a CBM+ Operational Concept Graphic.

  Architectural development generally begins with the creation of the OV-1. This pictorial representation provides the highest level and most comprehensive view of the CBM+ strategy. It is useful both for describing the general structure and component pieces of a CBM+ implementation and for supporting approval and resource justification of the initiative. CBM+ implementers may use a variety of graphical approaches for the OV-1 depending on the nature of the CBM+ effort and the target audience. After the OV-1 has been prepared and approved, the other architectural views are derived from this basic picture as greater levels of detail are determined.

Figure 3-8. CBM+ Generic Architecture Overview



- OV-5, the Activity Model, lists the operational activities performed in association with the architecture's scope. It graphically describes an activity's inputs and outputs along with who (role or organization) performs the activity. It also describes, to some degree, a sequence of events.

- OV-2, the Operational Node Connectivity Description, lists all the nodes that are referenced in the OV-5 along with their labeled information exchanges.

- OV-3, the Operational Information Exchange Matrix, details all the information exchanges that are labeled in the OV-2. An information exchange may explode from a single exchange to two or more—or many—exchanges between two nodes. All are referenced in the OV-3. The OV-3 may also list performance and security attributes that are required for an information exchange.

- SV-1, the Systems Interface Description, lists (graphically) all the systems (and their interfaces) that support the information exchanges in the OV-2 and OV-3.

- TV-1, the Technical Standards Profile, lists all the technical standards that are used to support the systems and interfaces shown in the SV-1. A CBM+ TV-1 profile identifies the open system standards planned for data management and exchange in the CBM$^+$ initiative.

Descriptions and examples of these documents, including their formats, are available at http://www.defenselink.mil/cio-nii/docs/DoDAF_Volume_I.pdf.

Additional information on technical architectural standards is available in the DoD Information Technology (IT) Standards Registry (DISR). DISR access is available online at https://disronline.disa.mil. A Public Key Infrastructure (PKI) Certificate is required. The DISR includes

- information for program managers with the capability to build standards profiles, known as Technical Views (TV-1 and TV-2); and
- a minimal set of primarily commercial IT standards and guidelines for use in the management, development, or acquisition of new or improved systems within DoD.

DISR standards are used within DoD as the “building codes” for all new systems. The standards are intended to facilitate interoperability and integration of systems within the Global Information Grid (GIG). DISR also provides the ability to specify profiles of standards that programs will use to deliver net-centric capabilities.

Putting the Pieces Together—A CBM$^+$ Architecture Approach

There are many system hardware and software components that, together, comprise the totality of a CBM$^+$ implementation of an improved maintenance capability. Developing a credible and comprehensive architectural depiction of the end-to-end condition monitoring and health management process greatly enhances the probability of achieving maximum effectiveness and interoperability of the component pieces of the overall process.

The architectural views should be created and validated as early as possible, and used as part of the effort to construct the total capability. As the initiative progresses and each successive detailed view is developed, the architecture becomes more useful, ensuring all component pieces are planned or in place, and the human interactions and information exchange requirements can be tested to ensure proper functionality, timeliness and accuracy. The architectural views also may be used to support management decisions to prioritize the development of different pieces of the total process, including the allocation of program resources.

The CBM$^+$ architecture may be implemented in several ways. The architecture may be developed independently or part of a larger system-of-systems effort. The implementing organization will decide whether to integrate the CBM$^+$ architecture into a larger system’s architecture; but ultimately, separate but interacting architectures must be compatible to achieve effective implementation.

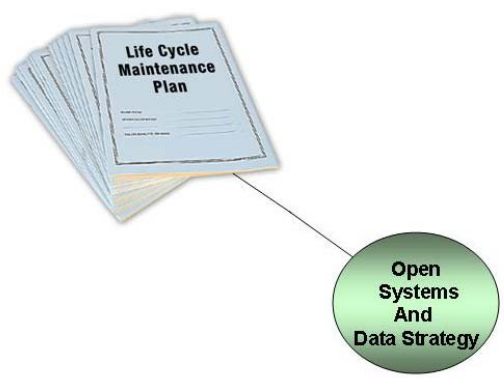
Validation and Verification

As part of the CBM+ development strategy, a validation and verification (V&V) strategy should be executed. V&V of CBM+ functionality is tied to the architecture products and is performed as an integrated review that validates the information exchange, process, and output requirements based on the operational and systems views that govern the manual processes and automated systems that accomplish data collection, exchange and analysis in conformance with the technical capabilities and standards as described by the architecture.

Initially, V&V is a matter of developing the models of the processes and then the modules themselves. V&V is first a simulation and modeling exercise of transmitting CBM+ data between models, accomplished in a systems integration laboratory setting. As the validation proceeds and the applications for software exchange are developed, V&V may then be accomplished between the platform and data storage or analysis sites by live demonstration. V&V will accomplish the following:

- Verification of fidelity of design to performance specifications
- Validation that the products and capabilities work as intended:
  - Data exchange between the platform and the enterprise is in conformance to open standards and data protocols
  - The CBM+ data strategy transmits the appropriate data
  - The data strategy facilities interoperability with third-party software applications that also conform to the key open standards and data protocols
  - Selected analytical capabilities provide effective human interfaces and credible results.

6. Open Systems and Data Strategy



The term “open systems” refers to the design of hardware, software, and business processes based on industry and government standards that are vendor- and equipment-independent. Open systems allow for interoperability, portability, and scalability. An open systems approach facilitates the use of widely accepted standard products from multiple suppliers. In addition, if the open system is defined by specifications, standards, and common processes used in the private sector, DoD can be one of many customers and leverage the benefits of the commercial marketplace; production and technical capabilities can then be competitively selected from multiple suppliers.

The system design flexibility inherent in the open-system approach, and the increasing availability of conforming commercial products, mitigates potential interface problems associated with DoD's legacy or proprietary systems. Finally, life-cycle costs are reduced by a standards-based architecture that facilitates upgrades by incremental technology insertion, rather than by large-scale system redesign.

A viable strategy for data management, storage, and exchange is another key technical component of a CBM$^+$ implementation. DoD's overall data management strategy is "to move from individually owned and stored data in disparate networks and within legacy systems/applications to an enterprise information environment where authorized known and authorized unanticipated users can access any information and can post their contributions for enterprise-wide access."[8] This means data are visible, accessible, and understandable. Shared data supports planned and unplanned consumers and shared meaning of the data enables understanding by all users.

Open Systems

The open-systems approach is an integrated technical and business strategy that defines key interfaces for a system (or piece of equipment) being developed or maintained. Specifications and standard interfaces generally are best defined by formal consensus (adopted by recognized industry standards bodies); however, commonly accepted (de facto) specifications and standards (both proprietary and non-proprietary) are also acceptable if they facilitate the use of hardware and software from multiple suppliers.

Open systems enhance the interoperability of a system within a family or system-of-systems concept, such as is typified in a CBM$^+$ implementation. An open-system standard is concerned primarily with interface compatibility to promote interoperability between multiple vendors' equipment, software, and databases. An effective open-systems approach, one that is applicable to most DoD CBM$^+$ applications, should apply open standards for all critical interfaces in the end-to-end system. These critical interfaces control the effectiveness and interoperability of system elements. Use of open standards also gives the CBM$^+$ implementer greater latitude in selecting health assessment software, including increasing the option to link or "bolt-on" multiple applications to support a variety of health assessment and predictive tasks. Open-system interfaces are often more cost effective (i.e. address cost drivers), and accommodate rapidly evolving technology and evolutionary requirements. Additionally, this approach reduces the amount of resources needed for subsequent modifications, which makes system upgrades quicker and more cost effective.

The open-systems concept is an essential element of CBM$^+$ because a comprehensive CBM$^+$ implementation often will be executed in an environment that includes different sensor technologies, multiple information systems, different data models, collection mechanisms across organizational boundaries, and different enterprise systems environments. To help integrate this disparate set of components, a number of commercial standards relating to CBM$^+$ information flows and related process elements have been established by the International Organization for

[8] Todd, Michael, Office of the Secretary of Defense, Networks and Information Integration, "DoD Data Strategy Briefing," October 20, 2005.

Standardization (ISO) and other standards management organizations, such as the Institute of Electronics and Electrical Engineers (IEEE) and Society of Automotive Engineers (SAE).

The Machinery Information Management Open Systems Alliance (MIMOSA)[9] also established specifications and data models in support of condition monitoring. These specifications can be applied as the basis for a supporting data strategy for a common CBM$^+$ operating environment. From a data management viewpoint, it is highly desirable that CBM$^+$ data exchanges and storage conform to the Open Systems Architecture for Enterprise Application Integration (OSA_EAI), the data flow hierarchy that is based on the open architecture standard published by MIMOSA.

Table 3-3 lists examples of standards available to CBM$^+$ implementers.

Table 3-3. Examples of Standards Available to CBM$^+$ Implementers

Area of application	Standard	Standards organization
Sets out guidelines for the general procedures to be considered when creating a condition monitoring program for machines, and includes references to associated standards required in this process. It is applicable to all machines.	17359:2003	ISO
Specifies definitions of terms used in condition monitoring and diagnostics of machines.	13372:2004	ISO
Establishes general guidelines for software specifications related to data processing, communication, and presentation of machine condition monitoring and diagnostic information.	ISO 13374-1:2003	ISO
Gives guidance for data interpretation and diagnostics of machines. Allow users and manufacturers of condition monitoring and diagnostics systems to share common concepts in the fields of machine diagnostics.	13379:2003	ISO
Industrial automation systems and integration—Product data representation and exchange.	10303 (Family)	ISO
Establishes the requirements for a data communication network interface applicable to all on- and off-road land-based vehicles.	J1850	SAE
Recommended practices for light, medium, and heavy duty vehicles used on or off road as well as appropriate stationary applications which use vehicle derived components (e.g. generator sets).	J1939 (Family of Standards)	SAE
Standard for Evaluation Criteria for Reliability-Centered Maintenance (RCM) Processes.	JA1011	SAE
A Guide to the Reliability-Centered Maintenance (RCM) Standard.	JA1012	SAE
Standard for a Smart Transducer Interface for Sensors and Actuators–Digital Communication.	1451	IEEE
Access control and physical characteristics for wireless local area networks.	802.11	IEEE
Open Systems Architecture for Enterprise Application Integration.	OSA-EAI	MIMOSA
Open Systems Architecture for Condition-Based Maintenance.	OSA-CBM	MIMOSA
Defines the mechanical, electrical and functional Characteristics of a serial data bus originally designed for use with military avionics.	1553	Military Standard

[9] MIMOSA is a not-for-profit trade association dedicated to developing and encouraging the adoption of open information standards for operations and maintenance in manufacturing, fleet, and facility environments.

Table 3-3. Examples of Standards Available to CBM+ Implementers

Area of application	Standard	Standards organization
A specification for creating technical publications using a Common Source Data Base (CSDB). Information is stored in the CSDB in small chunks, called data modules. The purpose of storing discrete chunks of information in the database is to promote reuse of the information in as many different technical documents as possible.	S1000 D	Air Transport Association, Aerospace and Defense Industries Association of Europe and Aerospace Industries Association

Additional information on standards and their applications as well as copies of specific standards can be obtained from the following:

- International Organization for Standardization (ISO) at http://www.iso.org/iso/en/ISOOnline.frontpage
- Society of Automotive Engineers International at http://www.sae.org
- Institute of Electronics and Electrical Engineers at http://www.ieee.org
- Machinery Information Management Open Systems Alliance at http://www.mimosa.org.

CBM+ implementers should use the sites of these standards organizations as a resource for obtaining information and copies of standards documents, often for a charge. Another useful source of standards and specification information is the Acquisition and Streamlining Standardization System Online (ASSIST-Online) site. ASSIST, the official source of DoD specifications and standards, provides access to current information about military and federal specifications and standards under the management of the Defense Standardization Program. ASSIST-Online provides access to standardization documents over the Internet and includes powerful reporting features, an exhaustive collection of digital and warehouse documents, and provides direct access to more than 104,000 digital documents in Adobe Portable Document Format. All ASSIST documents are available to users free of charge; however it does require an account and login.

To request an ASSIST-Online account, complete the online application format at assist.daps.dla.mil/online/registration. An ASSIST user account will be sent in one e-mail and a temporary password in a second e-mail. If problems are encountered with registering, send an e-mail to registration@astmail.daps.dla.mil or phone the ASSIST Help Desk team, (215) 697-6257, between 7:30 am and 4:00 pm Eastern Time (business days only).

The DISR mandates the minimum set of standards and guidelines for the acquisition of all DoD systems that produce, use, or exchange information. *DISRonline* consists of a collection of web-based applications supporting the continuing evolution of the DISR and the automation of all its processes. It supports all aspects of the DISR from standards development to daily usage and compliance guidance using a web-based front-end. It provides general information for the DoD IT Standards Committee, IT Standards Working Groups, and other DISR communities of interest, as well as access to all versions of the archived Joint Technical Architecture documents. Public Key Infrastructure certificates are required for *DISRonline* at https://disronline.disa.mil/.

CBM$^+$ implementers should be familiar with the ISO, MIMOSA, and related standards, as these represent considerable prior effort to structure a comprehensive and efficient approach to the accessibility and exchange of data across the component elements of a CBM$^+$ environment.

Data Strategy

It is essential that data strategies include the sharing of CBM$^+$ data across organizational boundaries and at all levels: tactical, operational, and strategic. Because of the variety of possible CBM$^+$ applications in DoD, there are a multitude of possible approaches to data storage and interchange. For most weapon systems or equipment, health management and related data will be stored on-board individual platforms or in data storage hardware at or near the sensor or input point. Aggregation of data may occur across the system or organizational hierarchy from the component to the platform to a CBM$^+$ data warehouse acting as an off-board data aggregation process performed at any level above the platform (e.g. tactical, operational, or national-strategic echelons). See also Figure 3-5.

The higher the level of the CBM$^+$ data warehouse, the more extensive the information it contains. For example, a tactical level CBM$^+$ data warehouse may collect failure data from the entire set of similar vehicles in an organizational unit. A CBM$^+$ data warehouse at the strategic level can provide data for assessing and predicting failures for different geographical regions, different climate and weather patterns, different areas of operation, or common systems. This multitude of applications and configurations emphasizes the need for careful attention to data standards and interoperable approaches to data storage, access, and communications. In the long term, adoption of the commercial and government data and process standards will facilitate availability and use of more standardized data for processing and analysis. The Services' implementation of more standard information systems, such as Enterprise Resource Planning applications, will also help standardize CBM$^+$ analytical activities across DoD.

In general, the degree of data management sophistication at each level of the system hierarchy will depend on the amount of health assessment and predictive activity required at that level. If an on-platform health assessment is required, data storage and access to support on-board assessment software will be needed. If such assessment is to be done off-platform at the tactical or even national level, then the data strategy will be less complex, perhaps including only real-time or even periodic data transmissions with little permanent storage or analysis.

CBM$^+$ Essential Elements Summary

The CBM$^+$ implementation strategy, usually for reasons of resource availability or competing priorities, will be incrementally adopted across different organizational echelons. In some instances, however, "bridge" or "placeholder" capabilities must be put in place to compensate for missing or less-than–full availability of key capabilities. Although this is to be expected, the CBM$^+$ implementer must recognize and convey to managers and customers that attaining the full benefits of the CBM$^+$ approach heavily depends on substantial implementation of the full range of CBM$^+$ capabilities.

All of the essential elements of a CBM$^+$ strategy should come together under an operating concept in which weapon system and equipment platforms are equipped with sensors and embedded health management systems. These systems monitor the current health of the platform or equipment; predict future changes in platform health; and report status and problems to the crew, tactical chain of command, operational commanders, and logistics providers (by way of the command and control and supporting logistics networks).

The embedded health management system uses information from on-system sensors and software to capture and store a detailed operating and maintenance history of the platform. It also uses a variety of automatic identification technologies on major components and other tools to maintain a system hardware and software configuration.

Operating history and configuration data are available from each system. This data transfer is automated and may utilize networks or wireless connections. The data exchange occurs either directly through a wireless capability on the system or indirectly using a wireless capability to a networked maintenance support computer used at or near the system. This target computer has server capabilities for data storage. It stores data that may be useful at the organizational level and it can forward the complete data set to an enterprise-level CBM$^+$ data warehouse.

The data warehouse is a comprehensive database that includes transaction, descriptive, technical, and historical records from various sources and is available to a wide range of users. Life-cycle managers may use the data to develop CBM plans, issue service advisories to maintenance personnel in the field, update prognostics algorithms, and identify the root causes of failures, cost and readiness drivers, and similar management-related activities. Equipment designers may use the data to plan product improvements. Depot repair activities use the data to tailor maintenance actions based on the condition and usage history of each component. Maintenance officers in field activities may access the data to plan maintenance for their assigned platforms.

Maintenance is performed to maximize operational availability and combat capability of operational units. Rather than being run to failure, components can often be replaced based on equipment condition and mission requirements. An embedded health management system on each system predicts the remaining useful life of components based on failure predictors derived from composite analysis across the range of deployed systems and the actual usage and stress history of individual or groups of components. Routine maintenance, such as the replacement of lubricants, coolants, and other fluids, may be based on the condition of the fluid rather than gross indicators, such as operating hours or calendar time.

Section 4.
Getting Started—CBM^{+} Implementation

Table 4-1 summarizes the basic steps for planning, implementing, and operating a CBM^{+} initiative or project.

Table 4-1. Getting Started Checklist

1.	Understand that CBM^{+} is a continuous improvement initiative over the life cycle of a weapon system or equipment.
2.	Ensure full understanding of the planning, implementation, and operations phases of CBM^{+} by the implementation team, functional managers, stakeholders, and customers.
3.	Initiate the CBM^{+} planning phase and complete the processes needed to develop a CBM^{+} strategy and to begin the selection of applicable technologies.
4.	Build on planning phase actions by managing the implementation phase as a time-phased execution of process changes, technology insertion, organizational realignments, and equipment changes.
5.	In the operations phase, incrementally deploy CBM^{+} capabilities to operational user locations and continue through full execution of required CBM^{+} capabilities.
6.	Continuously assess CBM^{+} progress and overcome barriers to successful execution as they occur.
7.	Discontinue or modify CBM^{+} capabilities for specific weapon systems and equipment as requirements evolve with the cessation of use or replacement of those capabilities.

This Section discusses the planning and implementation of CBM^{+} under the principles of CPI.[1] Later, under the heading of operations, it expands on approaches to managing an existing CBM^{+} initiative that has already been incorporated into a new acquisition program or implemented into a legacy system.

Under CPI, it is envisioned that the elements of CBM^{+} should be revisited as the life cycle progresses, conditions change, and technologies advance. Another useful reference, "Designing and Assessing Supportability in DoD Weapon Systems: A Guide to Increased Reliability and Reduced Logistics Footprint" stresses the recurring, life-cycle role of the PM in translating and refining the users' desired capabilities into actionable, contractible, and measurable system performance and supportability requirements.

Creating the CBM^{+} Environment

Successful implementation of CBM^{+} is more than going through a series of predefined steps. As with most significant change efforts, CBM^{+} implementers should take a holistic view of their initiative. This means creating an environment that is conducive to change, and consistently dealing with a multitude of issues that are certain to occur in the implementation process.

[1] Deputy Under Secretary of Defense (Logistics and Materiel Readiness), *Continuous Process Improvement Transformation Guidebook*, May, 2006.

The various implementation actions proposed in this Guidebook have been chosen within the context of a change management approach. The underlying elements of this approach are as follows:

- *Institutionalizing the initiative.* Accomplish actions that create the overarching framework and structure for CBM$^+$, including compliance with DoD policy and guidance.
- *Changing the environment.* Implement actions that focus on changing the technological capabilities and business processes within the maintenance environment, encouraging CBM$^+$ planning, advancing technology improvements, and analyzing the probability that planned actions will achieve CBM$^+$ objectives.
- *Synchronizing initiatives.* Execute actions to effect coordination among CBM$^+$ and other related initiatives, adopting established initiatives that display CBM$^+$ attributes, sharing lessons learned, encouraging team efforts to effectively advance CBM$^+$, and building on information systems integration solutions.
- *Investment justification.* Accomplish actions that improve the understanding and support of the investment required to achieve the goals of CBM$^+$, compiling business case and readiness analyses for justification support in the PPBS process.
- *Managing for success*. Consistently and continuously promote actions that help achieve progress toward CBM$^+$ goals and objectives.

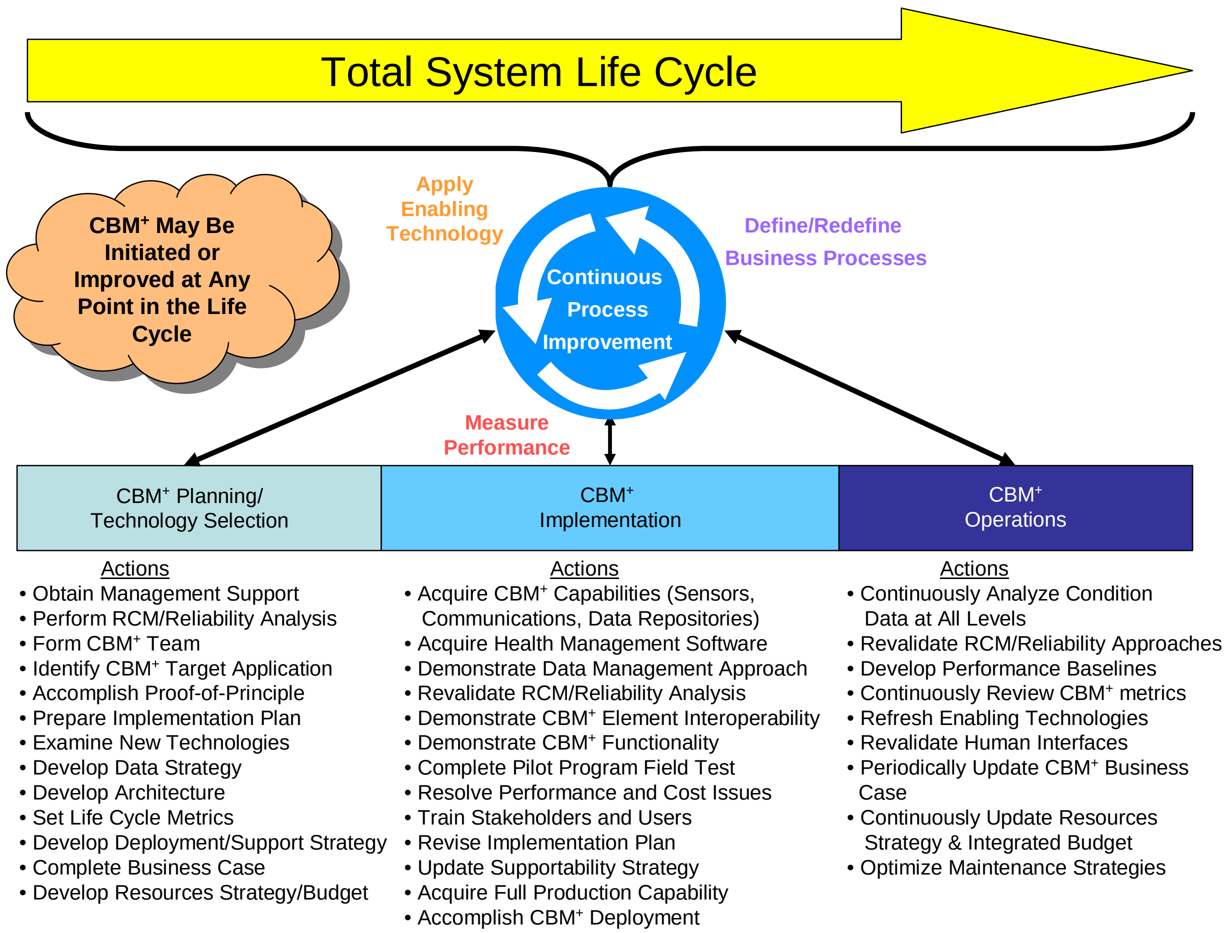
When pursuing CBM$^+$ implementation, PMs should keep these overall change management precepts in mind as they execute their plans.

CBM$^+$ and the Acquisition Life Cycle

The most effective and efficient maintenance plans are developed during the acquisition design phase of a weapon system or equipment and incorporate the correct processes and technologies up front. Because the pace of weapon system and equipment acquisition and phase-out is slow, this Guidebook needs to address the application of CBM$^+$ to the legacy environments of today. Equipment will not always be used as designed, so it may eventually fail in an unexpected manner and in unplanned time frames. Therefore, PMs should take advantage of CBM$^+$ opportunities to modify maintenance plans when possible and affordable, regardless of where the particular weapon system or equipment is in its life cycle. It is desirable when CBM$^+$ implementation can be executed in the context of a larger perspective, such as a common architecture or a system-of-systems environment. In this way, the CBM$^+$ strategy will be consistent with broader efforts, like the introduction of new weapon systems or equipment, process improvement initiatives, technology upgrades, or information system modernization.

CBM$^+$ implementation can be divided into three phases that complement DoD's total system life-cycle acquisition strategy: the planning phase, the implementation phase, and the operations phase. The technology aspects of this phased approach are discussed in Attachment A. The actions described in the remaining sections and subsections are not necessarily listed in a required sequence. As the life cycle progresses, some actions may be accomplished in a different order or even concurrently based on circumstances. Figure 4-1 shows the relationships among the planning, implementation and operations phases.

Figure 4-1. CBM$^+$ and the Total System Life Cycle



CBM$^+$ Planning/Technology Selection Phase

Planning actions generally apply when a CBM$^+$ initiative is first started within a particular organization. The initial efforts focus on familiarization with the CBM$^+$ concept, ensuring managers and employees at all levels understand CBM$^+$ and are supportive of CBM$^+$ objectives and planning, and developing the basic steps required to initiate the effort.

Obtain Management Support

One of the first important actions is to ensure full management support for the initiative. According to DoD policy, Military Components must include the CBM$^+$ strategy in appropriate requirements documents and ensure that defense acquisition programs exploit CBM$^+$ opportunities as system performance requirements during system design and development, and throughout the system's life cycle.

In today's DoD logistics community, most managers have been exposed to the basic concepts of CBM$^+$. Although these logistics managers accept CBM$^+$ (to varying degrees) for potential application in DoD maintenance activities, they often are unfamiliar with the specifics of the changes required and have not progressed beyond endorsing the principle in concept. CBM$^+$ proponents must work to market the concept; ensuring maintenance managers receive sufficient briefings on the CBM$^+$ strategy and its application to their organization. This is particularly important to maintain management's support for sufficient personnel and funding as the initiative progresses. At the same time, the customers of the planned CBM$^+$ initiative (e.g., the operators and warfighters) should be made aware of the potential effects and benefits of the planned changes.

Perform RCM and Reliability Analysis

A reliable system performs as designed in an operational environment over time without failure. Reliability is a primary focus during system design and architecture development. Reliability analysis considers trade offs among time to failure, system performance, and system life-cycle cost. This analysis is necessary to ensure the correct balance of these factors and maximize system technical effectiveness and, ultimately, affordable operational effectiveness. Options that must be considered and implemented to enhance system reliability include "derating" (defined as purposeful over-design to allow a safety margin), redundancy, and ease of reconfiguration.

The primary objective of reliability analysis is to minimize the risk of failure within the defined availability, cost, schedule, weight, power, and volume constraints. While conducting such analyses, trade offs must be considered and dependencies must be explored for system maintainability and supportability strategies, including CBM$^+$.

Types of reliability analyses include

- RCM;
- failure modes and effects criticality analysis, which identifies the ways systems can fail, performance consequences, and the support remedies for system failures; and
- fault tree analysis, which assesses the critical safety functions within the system's architecture and design.

Such analytical approaches significantly minimize the necessary logistics footprint and maximize system survivability and availability. The results of the initial reliability analysis will help designers, engineers, and logistics managers determine the applicability of implementing CBM$^+$ capabilities for specific weapon system or equipment programs.

Form CBM$^+$ Team

Today, few organizations have sufficient resident expertise with the skills required to implement a major process improvement initiative from inception to full deployment. For this reason, a team approach is generally recommended when executing something as broad as CBM$^+$.

Throughout DoD and in related parts of the commercial sector, the integrated product or process team (IPT) is an effective way of marshalling the personnel and skills needed to accomplish many improvement initiatives. As CBM+ requires participants with a variety of organizational, process, and technology skills, the CBM+ proponent should form an IPT early in the planning phase. It is important to realize CBM+ is not a one-dimensional discipline; bringing in only personnel focused on one aspect of CBM+ such as sensor technology or health assessment software will not provide the range of expertise needed for effective implementation.

At a minimum, the IPT should include personnel with expertise in the following areas:

- Weapons/equipment operations
- Business case development
- Systems engineering
- Reliability analysis
- Safety
- Data management
- Health management systems
- Maintenance organization
- Supply chain management
- Communications and networking
- Training and certification
- Performance metrics
- Maintenance management
- Process architecture development
- Sensors and AIT
- Budgeting and funding.

As the CBM+ initiative progresses, other competencies may be required to support implementation.

Identify CBM+ Target Application

Implementation of CBM+ requires significant up-front resources from a DoD maintenance organization. Clearly, sufficient resources may not be available initially to permit near-term application of CBM+ across the entire scope of weapons and equipment in a particular Service. This means CBM+ proponents should selectively focus, at least initially, on equipment with an anticipated high payback in improved performance, increased system life, more efficient maintenance capability, and overall reduction of life-cycle resource expenditures.

The Services have found that insertion of CBM+ enablers in new acquisition programs represents a “low-hanging fruit” opportunity. Embedding sensors and related technologies in the design and production phases of acquisition is usually more feasible and acceptable than retrofitting applications in fielded legacy equipment. As cited earlier, DoD policy requires acquisition program managers to “optimize operational readiness through affordable, integrated, embedded diagnostics and prognostics, automatic identification technology; and iterative technology refreshment.”[2] Adoption of new methods and integration of new technologies is generally more feasible earlier in the system acquisition phases. Later, the experience of “lessons learned” with new system acquisitions can be selectively applied to fielded legacy equipment as the requirement is defined and corresponding resources are made available.

[2] DoD Instruction 5000.2, *Operation of the DoD Acquisition Process*, May 2003, p. 13.

The alternative to focusing on implementing CBM$^+$ in new acquisition programs is to build the CBM$^+$ capabilities for “add-on” installation to fielded systems. This is particularly when large numbers of weapon systems or equipment are already operational and will be in the DoD inventory for extended periods. Other criteria for application of the CBM$^+$ strategy may include focusing on systems with the greatest maintenance workload or identifying components that could prevent the weapon system from performing its designed mission if they failed. Yet another approach could be to identify items that exhibit a decrease in the time between repair actions.

Legacy systems pose substantial challenges to the post-production implementation of CBM$^+$. Three particular problems are as follows:

- Installation of on-board (e.g., embedded) sensors often require substantial and costly modifications.
- Inadequate existing communications and data repository capabilities can frustrate data collection and condition analysis.
- Off-board (e.g., manual data gathering and analysis) capabilities may not be as comprehensive as required and could burden an already overworked maintenance workforce.

When adding CBM$^+$ to existing capabilities, implementers should concentrate on standardizing communications and data management technologies by maximizing the use of open-system standards, application of common health management software, and standardized training. This would permit a structured and orderly deployment of CBM$^+$ capabilities for multiple legacy equipment across several organizations.

Accomplish Proof-of-Principle

In light of the time and funding resources required for CBM$^+$ implementation, it is highly advisable for implementers to accomplish small-scale demonstrations of primary CBM$^+$ methods and technologies before full-scale implementation. A short-term pilot test that uses equipment likely to be used for later full implementation can be a low risk approach to ensuring the feasibility and benefits of the desired capabilities. Demonstration of CBM$^+$ planned methods and technologies gives managers a higher degree of confidence in the likelihood of future success. Implementers should conduct the test in the planned future environment using operational personnel whenever possible. Full documentation of test results will provide “real-world” information to support future Implementation Planning.

Prepare Implementation Plan

Implementation plans vary widely in scope, format, and level of detail. Implementers should use the format that best meets their needs, but bear in mind the requirement for credibility and ease of understanding by all potential readers. The following may be a good starting format for a CBM$^+$ plan:

- A comprehensive statement that covers planned scope of the CBM$^+$ application, including equipment, organizations, and functions.

- General supportability objectives (including outcome-related goals and objectives) for major maintenance activities to be covered.
- A description of how initiative goals and objectives—and the personnel, capital, information management, and funding resources required to meet those goals and objectives—are to be achieved, including a general description of the analysis of alternatives that lead to required operational and analytic processes, skills, and technologies.
- Requirements statements and planned design approaches for each of the six CBM+ essential elements described in Section 3 of this Guidebook.
- Identification of key factors external to the organization and beyond the organization's control that could significantly affect achievement of general goals and objectives.
- A description of the program evaluation process (including planned metrics) to be used in managing and evaluating progress toward achieving the desired levels of readiness and supportability within budget.
- A plan of action and milestones (may be developed in greater detail over time).

CBM+ implementation plans may differ from the format suggested above; however, a formal implementation plan must be prepared, fully staffed, and approved by appropriate levels of management before initiating further implementation actions. After management approval, the plan should be "sold" to major process customers and stakeholders. After initial approval, the plan will be expanded into greater levels of detail and include contracting approaches, particularly when the CBM+ architectural documentation is completed. An implementation plan template is available in Attachment B.

Examine New Technologies

The most difficult task for the CBM+ implementation team may be to correctly match available hardware, software, and supporting technology solutions to the requirements of the future maintenance process. This task must begin with the documentation of functional requirements. In the case of CBM+, the functional requirement can often be stated as the objectives (see Section 1 of this Guidebook) and business needs (Section 3 of this Guidebook). Once these requirements are recognized and approved for a specific organization or range of equipment, a comparative analysis will ensure the operational performance or benefits of adopting CBM+ methods and technologies can be assessed effectively.

Of course, no combination of technology is likely to provide the "perfect" solution. The team will need to make numerous compromises, trading off required capabilities against cost, time, and implementation difficulty. The decision to adopt a particular technology solution should never be based solely on the merits or appeal of the technology itself. Ultimately, the advisability of acquiring a particular technical capability relies on the contribution that acquisition makes toward improving one or more performance metrics or reducing cost factors.

Decisions on technology selection should always be made in the context of meeting functional requirements using the framework of business case alternatives. Further detail regarding applicable CBM^+ technologies is contained in Attachment A.

Develop Data Strategy

One of the first areas to be considered by the CBM^+ IPT should be the approach and mechanism for managing the condition and related data required to accomplish condition-based analysis whether on-, at-, or off-platform. Applying open systems or military standards will facilitate the integration of the various CBM^+ elements. It is advisable to complete the architectural interface views for data management, storage, and exchange as soon as possible. Acquiring software packages that are fully compatible with open data standards is also an essential part of a good data strategy.

Develop Architecture

Once the CBM^+ implementation plan has been approved, the IPT should begin constructing the architectural views, descriptions, and profiles as prescribed by the DoD Architectural Framework. As discussed earlier, the CBM^+ architecture becomes a key part of the implementation plan particularly when defining interfaces between the components of a comprehensive condition based maintenance process. Astute managers rely on the architectural representations to identify personnel training topics, assess progress for each process component, reallocate developmental resources, integrate different process components, and explain details of the initiative to outside reviewers. When required, a system's acquisition documents should be revised to incorporate CBM^+ functionality as it is described by the architectural views. Finally, the architectural design is a validation tool that ensures the final product is complete and satisfies the needs of the customer.

Set Life-Cycle Metrics

In creating the strategy for CBM^+ implementation, it is essential to identify and remain focused on strategic changes required to accomplish the transition to the desired CBM environment. Life-cycle sustainment metrics provide the quantitative tools to track CBM^+ implementation and operation. As the implementation effort progresses, high-level performance and cost metrics should be developed and supporting or diagnostic metrics[3] determined. Initially, however, the CBM^+ implementation team should identify which high-level metrics are required to monitor overall maintenance performance, costs, and results.

[3] Diagnostic metrics are measures that relate to specific elements of the maintenance process that must be quantified, managed, and improved to ensure achievement of overall performance and cost goals.

The CBM$^+$ implementation team should begin with metrics developed through recent research that used the "balanced scorecard" approach.[4] A quantitative baseline that uses past experience or estimated metric targets should be developed. The balanced scorecard approach requires measures in the following areas:

- Meeting the strategic needs of the enterprise
- Meeting the needs of individual customers
- Addressing internal business performance
- Addressing process improvement initiative results.

Implementation of CBM$^+$ requires a structured approach to measuring both the progress of implementation and the performance and costs once the CBM process is operational. Section 6 of this Guidebook provides a more detailed explanation of CBM$^+$ life-cycle sustainment metrics.

Develop Deployment and Support Strategy

CBM$^+$ deployment is a complex endeavor, especially when the user base is dispersed or there is a wide range of process or organizational configurations. The deployment plan is a critical element of the overall CBM$^+$ implementation strategy.

Implementers should announce the projected deployment schedule, including the expected training and installation dates. These announcements are important because managers and maintainers want to know how and when the changes will affect them. Respect the fact that deployment efforts are disruptive.

A well-documented yet flexible deployment plan is critical to success. Do not assume users will readily accept the inherent "goodness" of CBM$^+$ changes. Implementers need to understand to whom they are deploying new capabilities, their current work practices and policies, the amount of change they are willing to tolerate, and how CBM$^+$ will affect supportability once deployed. Generally, the larger the organization the more difficult it is to deploy changes due to cultural inertia. One approach is to work backwards when deployment planning. Envision the new process in operational mode and identify the steps needed to get to the level of supportability required by the operational customer to accomplish the mission. A good deployment plan includes go/no-go decisions points during the installation process. If installation simply isn't working, rollback the efforts and try to install again at a future date. Do not "go down with the ship." Capabilities to respond to process deficiencies, obtain user feedback and track metrics data should be part of the deployment approach. Data conversion will be a critical task for the deployment of new capabilities. It is a complex effort that should be started as early as possible consistent with fleet size or numbers of site locations.

[4] Robert S. Kaplan and David P. Norton, "The Balanced Scorecard—Measures that Drive, Performance," *Harvard Business Review*, January–February 1992.

Complete the Business Case

A business case is a document that identifies functional and supporting technical alternatives and presents economical and technical arguments for selecting alternatives over the life cycle to achieve the organization's business objectives or management direction. A BCA is one way of showing the advantage or disadvantage of implementing a CBM$^+$ strategy using both tangible and intangible factors. The CBM$^+$ implementation team should prepare a comprehensive BCA as a companion document to the implementation plan.[5]

In a CBM$^+$ initiative, technology choices become drivers of maintenance process change and equipment redesign. Because acquiring the technologies required for CBM$^+$ implementation will result in significant expenditures, the BCA is an essential tool to support management decisions and help justify program and budget inputs.[6] If the CBM$^+$ technology is removed or modified during the acquisition process, a BCA should be redone to measure the impact on life-cycle costs.

Develop Resources Strategy and an Integrated Budget

It is highly likely that CBM$^+$ initiatives will be viewed initially as a consumer of resources. Considerable investment will be required to include CBM$^+$ capabilities in new weapons and equipment or to "back-fit" CBM$^+$ onto legacy equipment. It is essential from the outset that CBM$^+$ be marketed with stakeholders and customers as an enabler of process improvement and a conserver of resources over the equipment life cycle. Early emphasis on building a credible business case will go far in justifying this perception, which also will be enhanced through careful attention to accuracy of programming and budgeting projections.

Depending on where in the life cycle the CBM$^+$ initiative is applied, applicable funding sources may be from research and development, procurement, or operations and maintenance appropriations. The manager must leverage potential CBM$^+$ performance, readiness, and cost benefits at each stage of the life cycle to maximize funding availability. However, a prudent manager will not overstate projected future savings. It is essential that CBM$^+$ implementers work closely with program and funds managers to ensure that funding requirements are thoroughly validated based on DoD policy requirements to implement CBM$^+$ and that requirements are reasonable, adequate, and likely to result in positive return on investment.

Of equal importance is the requirement to continually integrate, document, and track validated requirements in PPBS documents. CBM$^+$ managers should ensure validated resources are included in acquisition requirements documents as early as possible. A Service's program objective memorandum should specifically identify CBM$^+$ funding proposals. Similarly, programmed CBM$^+$ funds should be included in appropriate budget submissions. Finally, a diligent, integrated approach to tracking of CBM$^+$ requirements and funding throughout the PPBS cycle will minimize diversions of these resources to other competing needs.

[5] BCA learning module is available at https://learn.dau.mil/html/clc/Clc1.jsp?cl=.

[6] An excellent model for developing a CBM$^+$ business case is available at http://www.acq.osd.mil/log/lpp/product_support/final%20bcm.pdf.

CBM+ Implementation Phase

Building on the actions accomplished in the planning phase, the implementation team should manage a time-phased implementation of process changes, technology insertion, organizational realignments, and equipment changes. Clearly, these efforts are highly dependent on the availability of implementation resources.

The implementation of a CBM+ strategy will be, by necessity, incremental. This Guidebook stresses the requirement for comprehensive objectives setting and rigorous planning prior to implementation. Each implementation plan should dictate the sequence of actions and areas of emphasis. Once the planning phase is completed, then implementation should proceed according to the planned milestones. The following subsections outline the principle activities to be executed during CBM+ implementation.

Acquire CBM+ Technical Capabilities (Sensors, Communications, and Data Repositories)

The acquisition of the technical hardware infrastructure for a CBM+ initiative is one of the most visible and expensive elements of the implementation effort. While it is usually the responsibility of the technical or engineering community to select specific hardware components, logistics functional managers must participate to ensure selected technologies will meet operational needs and hardware components can be integrated into the overall architecture of the maintenance and other supporting processes. Consideration of availability of technology refreshment provisions is also important, as DoD tends to retain equipment considerably longer than the private sector.

DoD policy requires use of COTS solutions whenever possible. Cost considerations, return on investment, availability of sources, and delivery lead-times must also be monitored by the functional manager. Finally, selecting “leading-edge” technologies is not always the best solution. A good rule is to select technologies that meet, but do not exceed, functional requirements.

Acquire Health Management Software

Software acquisition should be subject to some of the basic guidelines applied to hardware in terms of interoperability, cost, and satisfying functional needs. Generally, CBM+ software components satisfy functional requirements. The documented business needs should drive software selection.

Although hardware and software must be compatible, software functionality should be validated first, with supporting hardware matched to complete the total package. In addition, functional managers should pay particular attention to human interface capabilities. The operational user will interact with interfaces built into the software components; therefore, overly complex or non-standard human interface techniques should be avoided. The key is to match software capabilities to specific functional requirements. The same COTS rules apply to software acquisitions.

Demonstrate Data Management Approach

Data availability is one of the critical concerns in many DoD process improvement initiatives. CBM is clearly a data-oriented process. Most CBM$^+$ elements are focused on improving data production, communication, storage, access, and use. Fortunately, thanks to technology, a multitude of data management capabilities are available.

Functional managers should maximize the application of data standards and foster a common understanding of data definitions across the CBM$^+$ components. Early attention to the CBM$^+$ architecture will be essential to an effective data management capability. A functional demonstration of the data management process to technical and operational (i.e., user) personnel should occur as early as possible in the implementation phase. This demonstration should include a review of a significant range of data in a "life-like" database and test runs of health management software against this test database. This is the beginning of building user confidence in the CBM$^+$ improvements.

Revalidate RCM and Reliability Analysis

As part of the implementation, a continuous review process will ensure periodic revalidation of initial reliability assessments. This is necessary to determine appropriate changes to maintenance approaches based on system re-engineering and redesign, equipment and component modifications, operational and mission changes, technological advances, and improved logistics capabilities. Based on the potential impacts of such changes, maintenance managers may wish to revise maintenance approaches and reallocate maintenance resources as indicated. Making such decisions on a timely and accurate basis will require full accessibility to documentation of prior reliability analysis efforts.

Demonstrate CBM$^+$ Element Interoperability

Interoperability should occur at each level of an effective CBM$^+$ environment. This means incrementally implementing the ability to share information and, for different elements, properly interact between the equipment platform and off-platform parts of the condition data collection and assessment elements and across enterprise organizational entities. Interoperability is best achieved through an "open systems" strategy that uses commercially supported practices, products, specifications, and standards, which are selected because of performance, cost, industry acceptance, long-term availability and supportability, and upgrade potential.

As hardware and software elements of a CBM$^+$ initiative are acquired and the data management mechanism is put in place, CBM$^+$ implementers should test the information exchange capabilities using as much of the full spectrum of condition data and analytical information derived from sensor sources as possible. Further, the interfaces between data repositories throughout the architectural environment and acquired analytic software should be thoroughly tested and demonstrated. The interoperability of CBM$^+$ hardware, software, and human interface components should be based on the approved architectural framework.

Demonstrate CBM$^+$ Functionality

Functionality means a process performs its principal tasks in accordance with the approved design, and inputs and outputs—whether automated or manual—are acceptable in terms of format, quality of content, processing volume capability, and timeliness. Once the component elements of a CBM$^+$ initiative are acquired and individually tested, the next step is to test and validate system inputs, outputs, and analytical products against approved metrics and quantified targets. This "end-to-end" functionality should be tested according to the CBM$^+$ architecture design.

The demonstration of functionality should assure the CBM$^+$ implementer that, when operational, the CBM$^+$ elements will produce results that are accurate, timely, and meet the expectations of the target user. The user community's representatives should also participate in the functionality demonstration. It is particularly important that the human interface of the initiative be demonstrated under "live" conditions to the extent possible.

Complete Pilot Program Field Test

Despite the rigor applied in controlled testing, there is no substitute for process testing in an operational environment. Pilot tests are a staple of DoD's approach to implementation of hardware, software, and functional capabilities. Pilot testing in the field permits the initiative to perform in a real-world setting, influenced by random influences and subject to conditions not included or even foreseen in the test environment.

A pilot test at an operational location also permits the intended users to participate in the new process under their own terms and in a familiar setting. However, the pilot test environment should still be a more controlled than actual operations. The following are among the elements of control:

- A comprehensive test plan structure should be followed.
- Test activity and results should be tracked and fully documented, including operational user comments.
- Input and output test data should be screened, with out-of-tolerance data clearly identified.
- Human operators should be well trained with hands-on oversight by the implementation team.
- A specific pilot test timeframe and ending date should be established.

Complete records of the activity and results of the pilot test must be maintained to ensure technical capabilities work as intended, and that cause-and-effect actions result in desired outcomes. This means, when CBM$^+$ capabilities are put in place, desired results (such as reduced mean down time, reduction of maintenance hours, reduced costs) actually occur. Documentation of pilot test results also helps assess whether the maintenance actions determined through reliability analysis are the most appropriate for the tested equipment or component.

Resolve Performance and Cost Issues

The demonstration and test efforts provide the input for modification of performance objectives and identify areas where additional costs or reallocation of resources may be necessary. CBM^+ implementers should ensure that needed revisions are documented and executed in funding programs and in updates to acquisition requirements documents for future program reviews. If resource changes cannot be made, then management should be advised of the impact on Implementation Plans. Revise all planning documents based on current management decisions.

Train Stakeholders and Users

Training is an important part of deployment. Remember, stakeholders may need training beyond learning how to work with the application. This may be the first time some users are working in a condition-based process. Similarly, it may be the first time users are working with a new technology but they need to be trained and educated in that technology to qualify them to work with CBM^+ capabilities.

Training plans and schedules should be consistent with implementation milestones. DoD policy requires training programs that emphasize approaches that enhance user capabilities, maintain skill proficiencies, and reduce individual and collective training costs. CBM^+ training plans should maximize the use of new learning techniques, simulation technology, embedded training, and distance learning systems that provide anytime, anyplace training and reduce the demand on the training establishment.

Revise Implementation Plan

It is important the CBM^+ implementation plan be kept current and aligned with management decisions, resource availability, acquisition of essential CBM^+ elements, and the attainment of milestones. Often changes outside the control of the maintenance organization will affect the CBM^+ implementation schedule. These fact-of-life conditions are common. By revising the implementation plan to accommodate such changes, the focus and credibility of the team will be maintained. Often, scaling back the scope of implementation or extending implementation target dates will be necessary. A flexible manager will use such setbacks to fine-tune planning or even chart alternate implementation strategies.

Update Supportability Strategy

Efforts to increase weapon system availability while reducing life-cycle costs and logistics footprint must include periodic assessments and, where necessary, improvements of the support strategy. System or equipment supportability is highly dependent on the maintenance plan. Revision of this plan through continuous analysis can help balance logistics support resources through review of readiness degraders, equipment maintenance data, maintenance program schedules and execution, and industrial coordination to identify and assess new methods and technologies. CBM^+ capabilities must also be modified if such changes are indicated by this analysis. Increases or decreases in acquisition and use of CBM^+ capabilities may also be appropriate if revisions to reliability analysis results occur.

Acquire Full Production Capability

This effort acquires the funded quantity of planned CBM+ capabilities and supporting materiel and services for the full initiative or for a significant increment. The full range of planning, acquisition, testing, and demonstration actions must be successfully accomplished prior to approval to acquire the full scope of CBM+ capabilities. Acquisition of hardware, software, and related items may be accomplished as a total package or according to an incremental acquisition plan based on best-value pricing and planned deployment schedules. If key components of planned CBM+ capabilities are not available for delivery, postponement of acquisition or delivery of related components should be considered.

Accomplish CBM+ Deployment

CBM+ initiative deployment should be executed in accordance with the Deployment and Supportability Strategy Plan. Elements of a CBM+ initiative should be an incremental or phased implementation across the planned environment. Implementers should ensure user organizations are fully prepared to receive and operate the planned CBM+ capabilities.

In addition to installation of the CBM+ capabilities, implementers should ensure mechanisms for correcting deficiencies, capturing user feedback, and tracking performance and cost metrics are in place and operating. Once a complete or significant portion of a CBM+ capability is in operation, a post-deployment “lessons-learned” report should be prepared.

CBM+ Operations Phase

The Operations Phase of a CBM+ initiative begins with the deployment of the first significant increment at an operational user location and ends with the cessation of use or replacement of the CBM+ capability.

Continuously Analyze Condition-Related Data at Component, Platform, and Enterprise Levels

The CBM+ strategy envisions a long-term maintenance approach that is based upon more effective collection, analysis, and use of CBM information. The deployment of a CBM+ capability in an operational and maintenance environment should be viewed as a permanent way of doing business over the life cycle of a weapon system or equipment. By acquiring and installing sensor-based technologies and data management, and by providing the ability to analyze collected data and produce effective decision support information, the CBM+ strategy will become institutionalized across DoD’s maintenance community. To achieve this objective, implementers must continue to pursue the development and installation of all of the essential elements of CBM+ across the broadest possible range of weapons, equipment, and maintenance organizations.

Revalidate RCM and Reliability Approaches

DoD policy prescribes CBM as the preferred maintenance approach; however, as circumstances change, maintenance managers should reassess condition-based strategies and use of CBM$^+$ enablers to ensure a positive return on investment and the most effective approach to satisfying customer maintenance requirements. Continuous monitoring of performance and cost metrics is one way of accomplishing these tasks. Managers should regularly review the results of reliability-based support decisions and realign maintenance analysis and execution approaches as required. This is particularly important over time as equipment ages or is modified, missions change, and technology advances. Such changes to equipment and utilization factors may also suggest the need to revisit applicable maintenance plans.

Develop Performance Baselines

The single greatest impediment to assessing the results and impact of a CBM$^+$ initiative is the lack of current and credible platform, fleet, and organizational performance, and cost data over a period sufficient to support maintenance decisions. CBM$^+$ practitioners should build into their initiative the capability to collect, track, and assess a baseline of equipment maintenance information sufficient to populate and continuously update performance and cost metrics databases. As the old adage goes, "What gets measured gets done." Establishing a historical data repository of key CBM$^+$–related performance and cost information is essential to supporting maintenance programming and budgeting submissions, BCAs, and validation of maintenance strategies.

Continuously Review CBM$^+$ Metrics

Effective management of any process requires accurate and timely quantification and measurement of results. For DoD logistics activities, such measurement relies on relating available resources to readiness at the best cost. Maintenance managers should recognize that metrics are essential when assessing and tracking the progress and results of a CBM$^+$ initiative.

As CBM$^+$ initiatives are implemented, it is important to track progress against DoD enterprise objectives to ensure the effort is meeting management's expectations.[7] Specific CBM$^+$ metrics should be consistent with and supportive of the following operational and force readiness objectives:

- Maximize readiness and availability of weapon systems and equipment.
- Improve reliability of weapon systems, equipment, and components.
- Reduce life-cycle ownership costs.
- Reduce mean down time.

The challenge is not the lack of data; oftentimes, the challenge is a surplus of data, or the lack of useable data to make informed, strategic decisions at the right time. Implementers often collect data to

[7] Section 6 describes a series of life-cycle sustainment metrics applicable to CBM$^+$ implementation and operations in greater detail.

track individual, discrete performance, cost, or customer satisfaction measures. To really have an impact, they need to compile, analyze, and act on the metrics data in an integrated, systematic, and long-term way. Effective managers take time to review their key metrics and validate maintenance actions or change course when necessary. Having an overall metrics utilization strategy will help accomplish this.

A plan for evaluating the CBM$^+$ initiative through quantifiable metrics will help. That plan should include the following steps:

- Identify what metrics to use and the required data.
- Collect only the data needed to make informed decisions.
- Identify priority "action areas" for improvement, measure the impact of those actions, and keep your stakeholders and customers satisfied.
- Determine benchmark objectives and performance goals you should aspire to and the extent to which they are being achieved.
- Evaluate whether an acceptable return on the investment is being obtained.

Metrics can be used effectively to direct or reassess CBM$^+$ management efforts and to evaluate how well the CBM$^+$ initiative is helping achieve the organization's mission.

Refresh Enabling Technologies

Rapid technological advancement requires a prudent technology refreshment strategy to provide long-term, cost-effective support and operations and to upgrade CBM$^+$ components ahead of the obsolescence curve. Health management software and diagnostic and prognostic capabilities will likely experience order-of-magnitude advances in the next several years. What is needed is a proactive approach to managing technology updates based on the following objectives:

- Improving technology surveillance. Provide a mechanism for proactively assessing the obsolescence of technologies and a mechanism to influence technology planning based on likely future developments in technology.
- Leveraging commercial industry technology advancements to reduce system cost, while increasing system reliability, growth capacity, and performance.
- Minimizing product obsolescence impacts on the CBM$^+$ capability through proactive modernization planning.
- Developing credible technology refreshment planning schedules for selected system-critical products.
- Building and maintaining a knowledge base that contains information (e.g., lessons learned) that can be easily accessed to support technology refreshment planning.

At the same time, CBM$^+$ implementers should understand the downsides to technology refreshment, such as expensive modifications and increased configuration management for multiple versions of software and hardware. An updated business case will help support refresh

Revalidate Human Interfaces

The American culture has strong faith in technology to overcome many obstacles and help with almost any job. DoD has an unfortunate history of mismatches between technology capabilities and the ability of human operators to properly understand and make the best use of these technologies and the information they produce. Adequate training can often be the solution to such problems; however, periodic reviews of manual input and output procedures and the utility of system management and operational products will sometimes reveal human interface deficiencies.

Although CBM$^+$ moves a maintenance organization closer to a more fully automated environment, ultimately human decisions are required to fulfill the complete maintenance action. Interface revalidation should be accomplished at all levels of the CBM$^+$ process, from the platform to high-level decision-support systems. By ensuring information provided to operators and managers is credible, timely, easily understood, and relevant to the decision process, CBM$^+$ capabilities will more effectively contribute to an effective maintenance program.

Periodically Update CBM$^+$ Business Case

The initial business case is an essential element for justifying a CBM$^+$ initiative. As the life cycle of the system or equipment progresses, it is a good practice for maintenance managers to revisit the business case to see if the factors validating a particular level of CBM$^+$ implementation are still applicable. This also is a good opportunity to determine if the original planned performance is being achieved and if projected return on investment has occurred. A full formal business case may not be required, but an informal revisit of the BCA may help fine tune the long-term CBM$^+$ strategy and to provide quantified justification for revised inputs to budget updates.

Continuously Update Resources Strategy and Integrated Budget

CBM$^+$ managers must continuously review and update their strategies for funding the initiative over its life cycle. Resource requirements to maintain and update CBM$^+$ capabilities will change as new weapons and equipment are fielded, maintenance plans are revised, new technologies are developed, and reliability assessments are modified. It is also necessary to market the CBM$^+$ strategy as stakeholders and customers change to ensure management’s continued support. Further, program and budget documentation should be updated for the entire financial program cycle to maintain adequate levels of resources. This includes phasing out investment for weapon systems, equipment, and major components at the end of their operational life cycle.

Optimize Maintenance Strategies

Despite the best efforts of planning and implementation managers, the CBM+ initiative will require redirection and modifications in the operational phase. New policies and procedures, operational experience, technology updates, mission and organization changes, funding availability, and other factors will necessitate reassessment of a number of the initial approaches. From initial deployment, it is advisable to document the lessons learned and to look for new ways to improve CBM methods and adopt updated enabling technologies.

This approach to CBM+ promotes the reliance on a CPI management strategy. Under CPI, management and employees continuously revise the current processes and, once they have been mastered, establish more challenging objectives. Improvement can be broken down between innovation and evolutionary change:

- Innovation involves significant improvements to existing processes in a relatively short time and may require large investments.
- Evolutionary change focuses on small improvements over time as a result of coordinated continuous efforts by all employees.

Effective CBM+ managers watch for opportunities for both innovative and evolutionary improvements. They adjust or revise plans as required to achieve desired results. Once the reason for a deviation is determined, they adjust plans to get it back on track.

Since deviation in outcomes may be positive or negative, change involves either rescuing strategies that are not working or are not being properly implemented, or making adjustments that help an organization capitalize on strategy overachievement. If the strategy is underachieving, small adjustments are often sufficient to get a planned improvement back on track. These adjustments often involve changing the timeframe for achieving a milestone or downscaling the quantity or quality of the planned initiative. In most instances, the entire approach should not be abandoned. If the strategy is overachieving (that is, if it is ahead of its target achievements), adopt a more ambitious new objective for the same timetable. In any case, managers should ensure any changes to CBM+ strategy are fully documented in official maintenance plans.

Section 5.
Managing a CBM$^+$ Initiative or Project

A CBM$^+$ Program Review Checklist

CBM$^+$ planning and implementation may be initiated at any point in the acquisition life cycle from the concept refinement to the sustainment phase. The initiative manager must be prepared to describe, market, and justify the CBM$^+$ strategy and required resources for reviewers, stakeholders, and customers. Table 5-1 is a suggested PM's review checklist for responding to questions and issues likely to be raised as part of the periodic life-cycle oversight reviews of a CBM$^+$ initiative.

Table 5-1. CBM$^+$ Program Manager's Checklist

Area	Issue
Policy	Is this CBM$^+$ implementation fully consistent with and supportive of DoD and Service policy and direction?
Requirements identification	Is this CBM$^+$ implementation based on approved business needs? Have the strategy and implementation actions been documented in joint requirements documents?
Resources strategy	Have BPAs been completed for each initiative? Have the best-cost funding requirements from the BPA been documented in the integrated program or budget submissions?
Implementation strategy	Has the implementation strategy been documented and approved by management, stakeholders, and customers? Has a CBM$^+$ implementation and deployment plan of action and milestones been published? Does the implementation strategy include interrelationships with other DoD and Service initiatives, such as TLCSM, PBL, Systems Engineering, or Focused Logistics?
Reliability relationship	Has a reliability analysis been completed for the target weapon system, equipment, or components?
Technology applications	Have all applicable technology applications been identified from both public and private sources? What diagnostic or prognostic capabilities are included in this initiative? Have technology demonstrations been accomplished to ensure specific applicability, interoperability, and functionality?
Architecture and data strategy	Has an architectural description of the CBM$^+$ initiative been developed? Has a data management strategy for all organizational levels been developed and tested? Are accepted data and information standards planned for information storage and exchange?
Metrics assessment	Have performance-driven objectives and best-cost metrics been developed for this CBM$^+$ implementation? Are metrics for availability, reliability, mean down time, and ownership costs provided?
Human factors and interfaces	Does the CBM$^+$ team have sufficient training and technical skills? Does the CBM$^+$ implementation strategy fully consider human interface requirements?

Table 5-1. CBM^+ Program Manager's Checklist

Area	Issue
Continuous process improvement	Does the CBM^+ implementation strategy full consider CPI techniques such as Lean, Six Sigma, or Theory of Constraints? Does the life-cycle planning strategy include provisions for process and technology refreshment? Are there provisions for maintenance plan optimization based on changing operational requirements, reliability changes, equipment modifications, or funding changes?

A CBM^+ Management Approach

An important prerequisite of a CBM^+ implementation is the need to change significant elements of the maintenance environment to facilitate the adoption of CBM^+ enabling capabilities. Such change occurs over time in an incremental, phased fashion based on CPI tenets. The CBM^+ initiative requires a life-cycle perspective and a long-term management commitment.

Each phase of a CBM^+ initiative will benefit from a continuous review of objectives, ongoing and planned activities, and results. An outcome assessment affords the opportunity to measure progress and whether the desired effects are being achieved. Using a sailboat metaphor, the captain keeps checking the course position and adjusting the sails and rudder as necessary to keep the craft on course.

An evaluation begins with a comparison of actual implementation strategies results against targets (objectives and key results). Monitoring provides the opportunity to adjust strategies, resources, timing, or other factors to keep a plan on track. Monitoring usually is continuous, with formal evaluation reports periodically reviewed by key managers.

In a broad context, managers should continuously ask three kinds of questions as part of a common sense management approach:

1. Are the strategies and actions accomplishing the desired goals and objectives within target ranges of results? If not, what adjustments may be necessary?

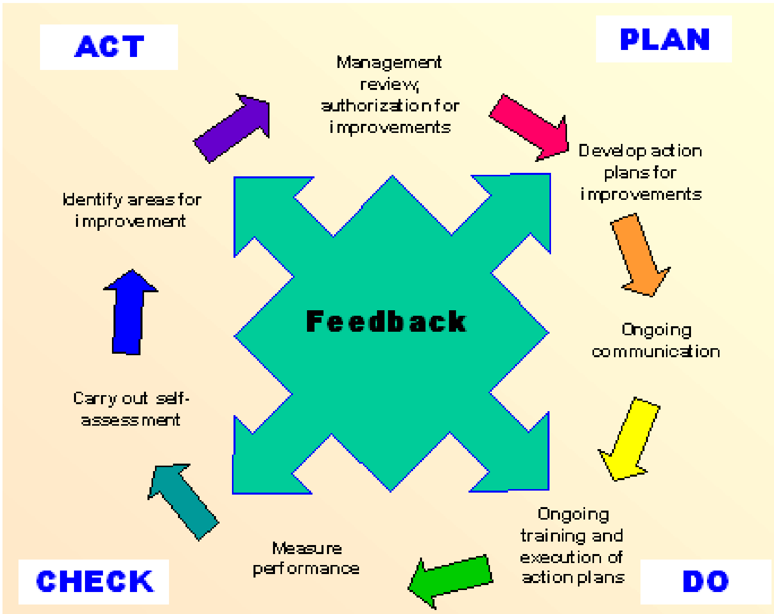
2. Are other adjustments required with respect to internal strengths and weaknesses?

3. Are other adjustments required with respect to changing external conditions and opportunities?

The elements of a CBM^+ strategy, as outlined in this Guidebook, can be implemented successfully only with a concerted application of effective management approaches to the initiative. CBM^+ implementers should not view their efforts as a technology application. Since the technologies work, they should concentrate on managing the initiative using CPI strategies.

One management approach that is particularly applicable to a CBM+ initiative is the Plan, Do, Check, and Act model (PDCA).[1] This approach is described graphically in Figure 5-1.

Figure 5-1. Plan, Do, Check, and Act Model



The PDCA model forms a never-ending cycle, and every step is equally important. It is a process-thinking model with several key components: resource commitment; training and culture change; assessment; communications; and documentation. Making the model work requires substantial and continuous commitment on the part of management. The following are among the management strategies that are essential to a PDCA effort:

- Ensure cross-organizational involvement throughout design, development, and implementation.
- Remember that implementation consists of all the steps, not just Plan and Do. Be willing to expend the same resources on assessments and continual improvement as expended on planning and development; doing less is false economy.
- Promote a process mentality instead of a project mentality. Avoid "check the box activity." Help people understand the initiative will never be "finished" because there will always be better ways to do things, or better things to do.
- Maintain consistent leadership. Continuity and strong support from senior management is crucial. One way to protect from unexpected leadership changes is to make sure everyone at every level of the organization is continually "dipped" in the initiative. In a process that really works, leadership can change but the system moves forward because the new leaders are as immersed in the process as the ones who left.

[1] The PDCA model originated in the 1920s and was popularized after WWII by the renowned statistician W. Edwards Deming. This discussion of the model was adapted from a "grey paper" on "Implementation Management" prepared by George Pilko and Associates Inc, at http://www.pilko.com.

- Maintain a flexible, effective organizational structure throughout implementation. Continuous communication throughout the chain of command is vital, as is employee feedback.

- Employ quantifiable measures to track your progress, not “punitive” measures, such as injuries, spills and violations. Use measures that will track the right things to get the initiative embedded into the organization? See Section 6 for management measures.

Remember, CBM$^+$ implementation is not about technology. It is about helping employees and organizations perform the way management wants them to perform and helping them to achieve the organizational mission.

CBM$^+$ Relationships with Other DoD Efforts

Organizationally and functionally, only a few efforts in the DoD truly “stand alone.” Relationships among different efforts may be based on process dependencies, mutual objectives, commonly used technologies, shared resources, or organizational linkages. CBM$^+$ implementers should stay current on related or similar activities, both to help ensure common objectives and to benefit from “lessons learned” whenever possible. Some of the key current DoD-wide initiatives that may impact or complement the CBM$^+$ includes the following

- TLCSM
- RCM
- PBL
- Systems Engineering
- Information Technology Portfolio Management
- Focused Logistics
- Sense and Respond Logistics.

CBM$^+$ and Total Life Cycle Systems Management

Under DoD’s TLCSM initiative, PMs are responsible for the overall management of the weapon system life-cycle support, including the following:

- Timely acquisition of weapon systems meeting warfighter performance requirements

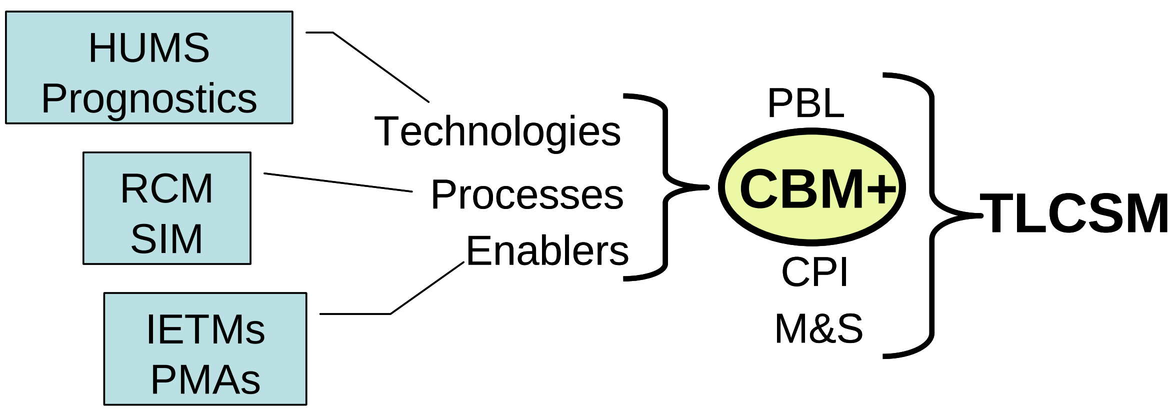
- Integration of sustainability and maintainability requirements during the acquisition process

- Life-cycle weapon system and equipment sustainment to meet or exceed warfighter performance requirements at best value to DoD.

TLCSM implementation is an incremental and continuous effort to ensure all valid support requirements are identified and included in requirements and funding programs at each acquisition milestone. Section 3 described the primary CBM+ elements that should be incorporated into the program milestone documentation to ensure CBM+ requirements are institutionalized as part of the acquisition program development, review, and approval process.

CBM+ contributes to a number of process improvement initiatives (such as the ones outlined below) to attain the life-cycle support objectives of system effectiveness and affordability. As an example, CBM+ capabilities feed into TLCSM, as shown in Figure 5-2.

Figure 5-2. TLCSM Relationship



Note: HUMS = Health and Usage Management System; SIM = Serialized Item Management.

CBM+ and Reliability Centered Maintenance

RCM is an analytical process that assists maintenance managers in determining appropriate methods of maintenance when considering costs, accuracy, and availability of required data, and the specific failure mechanism being analyzed. Opting for condition based maintenance strategies is one possible outcome of an RCM analysis.

The synergy between RCM and CBM+ relates to the use of applicable CBM+ technologies and methods to support management decisions for selecting and executing maintenance tasks. By linking RCM and CBM+ as complementary management tools, maintainers can significantly strengthen the rationale for choosing the most technically appropriate and effective maintenance task for a component or end item. In particular, the availability of timely and accurate condition assessment data made available through CBM+ capabilities will inevitably improve the RCM analytical determination of failure management strategies.

CBM+ and Performance Based Logistics

Performance-driven outcomes means the performance of all provider activities is measured against clearly defined outcomes at the weapon system level. Within that context, PBL is an approach for weapon system and equipment support that employs the acquisition of support from “best value” sources as an integrated, affordable performance package designed to optimize system readiness. As

CBM^{+} helps focus the maintenance process on maximizing weapons and equipment readiness with optimum resource allocation, it fully complements the PBL concept. In fact, it becomes an essential factor in attaining the performance-based objectives in the area of maintenance. DoD policy prescribes PBL as the preferred product support strategy.[2] CBM^{+} tools, technologies, and processes achieve desired outcomes through continuous improvement of weapon system performance and availability, along with a reduction in ownership costs.

CBM^{+} and Systems Engineering

Systems engineering is the overarching process that a program team applies to move from a required capability to an operationally effective and suitable system. Systems engineering processes are applied early in concept refinement, and then continuously applied throughout the system's life cycle. PMs and life-cycle logisticians should consider the effect system development decisions (such as the application of the CBM^{+} strategy) will have on the long-term operational effectiveness and the logistics affordability of the system. The cost to implement a system change, including supportability enhancements, increases as a program moves further along its life cycle. CBM^{+} has the greatest leverage in the early stages of development, when the program design is most flexible. The life-cycle logistician must ensure CBM^{+} implementation is addressed in the system's design and also ensure the maintenance support concept and plans will be flexible and responsive enough to support the design and resultant or evolving system. The ability to ensure affordable support is dependent upon whether reliability and maintainability and the necessary tools and information (such as prognostics and diagnostics) are built in during system design and procurement. Thus, it is essential that CBM^{+} managers actively participate in the system engineering IPTs to ensure maintenance approaches are balanced with program schedule, technical performance, and cost objectives.

CBM^{+} and Information Technology Portfolio Management

In its basic form, information technology (IT) portfolio management attempts to gain comprehensive management control of the full range of IT projects within an organization. The objectives are to ensure projects match organizational strategic goals, prioritize projects and resource allocation, and continuously manage a group of IT projects in a holistic and continuous manner. Implementers should ensure CBM^{+} hardware, software, and related technology requirements are identified and included in their organization's IT portfolio management process. The CBM^{+} implementation strategy should consider IT applications documented both within their own Service and in other Service, agency, and commercial portfolios to identify any joint-use software or supporting technology applications. Making full use of joint-use applications will enable CBM^{+} funding requirements to compete more effectively.

CBM^{+} and Focused Logistics

Focused Logistics (FL) is a comprehensive DoD initiative to transform logistics capabilities in support of future joint forces and operations. FL capabilities are fully integrated, expeditionary, networked, decentralized, adaptable, and supportive of decision superiority. Focused Logistics represents the future warfighter's perspective of logistics requirements. One sub-requirement of

[2] DoD Directive 5000.1, *The DoD Acquisition System*, May 12, 2003, Enclosure 1.

FL is Agile Sustainment, which is the ability to provide materiel, facilities, services, and other support to maintain readiness and enable operations until successful.[3] Agile Sustainment specifically cites system health monitoring and diagnosis as an FL requirement. It also identifies CBM+ as the implementing strategy to satisfy this need.

CBM+ and Sense and Respond Logistics

Sense and Respond Logistics (S&RL) is a transformational network-centric concept that enables joint operations through precise, agile support. S&RL relies on highly adaptive, self-synchronizing, and dynamic physical and functional processes. It predicts, anticipates, and coordinates actions, and logistics capabilities that ensure rapid and responsive support for military operations across the strategic, operational, and tactical levels of war.[4] S&RL depends on sophisticated IT support to enable data sharing, early intelligence, commitment tracking, predictions, adaptation, and cognitive decision support. Under the S&RL concept, most military end-items and systems will be equipped to sense potential component failures or consumables support status. This use of technological tools to detect conditions and support reactive decisions to such conditions in advance of failure or other undesired results is fully consistent with CBM+ precepts. In the long term, S&RL will expand predictive capabilities across the spectrum of logistics functions. CBM+ is an initial application of the S&RL concept.

Overcoming Barriers to CBM+ Implementation

Organizational resistance to change is common in any endeavor. Most DoD personnel are comfortable doing things in familiar ways that were learned through experience. Although change is often mandated by management, effecting real and permanent change occurs when the practitioners of a given process understand the reasons for change, the benefits to be obtained, and how their jobs can be made easier or how results can be more effective. Attachment C discusses some elements of resistance to change that are likely to be encountered in a CBM+ implementation.

Twenty Questions a Manager Should Consider

Implementation of CBM+ is not a single event. It is an evolutionary effort that progresses incrementally. DoD managers at all organizational levels, including logistics activities, PMs, depot- and field-level maintainers, and operational commanders face similar management issues during CBM+ implementation. A good manager periodically steps back, reviews the organization's progress, and assesses the initiative results to date.

As the CBM+ initiative progresses, the following questions should be asked:

1. Have I correctly identified the right CBM+ requirements and implementation actions based on desired operational outcomes that reflect stakeholder requirements?

2. Do I understand the relevant CBM+ policy guidance, including the TLCSM concept?

[3] Under Secretary of Defense memorandum, "As-is Focused Logistics Roadmap," attachment entitled "Focused Logistics Roadmap," November 9, 2005.

[4] DoD Office of Force Transformation, *Operational Sense And Respond Logistics Concept*, May 6, 2004.

3. Have I identified to leadership defendable estimates of the probable end-state results of the CBM$^+$ initiative based on quantified analysis?

4. Do I have the right people for my team?

5. Do I have adequate training for the team?

6. Does the implementation approach represent the varied interests and objectives of stakeholders and customers?

7. Are the implementation and operating tasks sufficient to cover the breadth of the strategy, and are they tied to a relevant organizational strategic plan?

8. Have I properly used reliability analysis?

9. Does the action plan accommodate the requirements and can it be achieved in a reasonable amount of time?

10. Do the implementation tasks and measures flow directly from applicable operational requirements incorporated into applicable acquisition requirements documents?

11. Does the continuous assessment strategy provide a clear view of the road ahead, and does it point directly to the desired results?

12. Do I have a management approach that is agile and flexible enough to account for changing conditions and environments?

13. Have I implemented clear and measurable metrics for availability, reliability, mean down time, and ownership costs based on a solid, defendable set of policy and doctrinal approaches likely to achieve DoD’s operational and force readiness objectives at the best cost?

14. Have I identified promising implementation alternatives in response to resource changes?

15. Have I found any breakthrough capabilities? Can I describe practical uses for them?

16. Have I developed a capabilities-based BCA with defendable results based on readiness objectives and best cost?

17. Are the resource estimates (based on the affordability and technical feasibility) of my planned implementation approach included in an integrated budget submission reasonable?

18. Do I have a good architectural framework?

19. Have I generated a compelling set of actions for each implementation milestone that gives decision makers a real set of options?

20. Have I identified excess capabilities resulting from CBM$^+$ implementation, and do I have an organizational plan for bringing them forward?

Section 6.
Measuring Success

Table 6-1 summarizes the basic characteristics for identifying, collecting and using key metrics for effectively measuring the implementation and operation of CBM^+.

Table 6-1. Measuring Success Checklist

1.	Are selected metrics imposed on the organization that controls the process producing and tracking the metric?
2.	Do users (i.e., management, customers, and stakeholders) accept selected CBM^+ metrics as meaningful?
3.	Do the metrics show how well goals and objectives are being met through CBM^+ processes and tasks?
4.	Do selected metrics measure something useful (valid), and measure it consistently over time (reliable)? Do they reveal a trend?
5.	Are selected metrics defined clearly and unambiguously?
6.	Is there an established, quantified baseline for comparison and analysis?
7.	Is an economical data collection and access capability in place or planned? Are metrics data timely and accurate?
8.	Is there a clear cause-and-effect relationship between what is measured and the intended use of the information as a management decision support tool?

Management information currently available to DoD logistics managers usually falls into one of three categories: workload, current resource expenditure and outputs, and performance compared to standards and goals. The CBM^+ implementation team should identify measures that will give managers and customers a consistent and quantifiable picture of maintenance performance and related costs.

Although no single set of performance measures is universally appropriate for every organization or every organizational level, significant strides have been made to identify basic enterprise-level metrics for DoD logistics activities. Once metrics are identified and a baseline of credible data is accumulated, the implementation team will use these metrics to help form the initiative and ultimately manage the CBM^+ maintenance capability that will deliver the required level of performance in future logistics operations. Metrics for CBM^+ fall into two categories:

- Implementation metrics
- Operating metrics (i.e., readiness and costs).

Implementation Metrics—How to Measure a Successful Implementation

Implementation metrics quantify the degree of progress toward a successful CBM^+ implementation. The measurement process involves selecting what is to be measured and then tracking progress toward the implementation of the selected area. A basic approach to selecting implementation metrics starts with the essential elements of CBM^+ (as discussed in Section 3 of this

Guidebook). A capability scorecard should be developed as a companion to the more detailed implementation plan. This scorecard is a simple checklist of the principal areas to be implemented as part of your CBM$^+$ initiative along with key completion milestones. An example of a basic capability scorecard is provided in Table 6-2.

Table 6-2. A CBM$^+$ Capability Scorecard

Implementation area	Implementation action	Milestones completed
Hardware	Acquire and install embedded sensors, built-in-test, built-in-test-equipment, data storage and retrieval equipment, and integrated electronic data exchange mechanisms (buses).	
Software	Acquire decision-support and analysis capabilities, diagnostics, prognostics algorithms, and health management.	
Communications	Implement databases and off-board interactive communications links.	
Design	Use open systems architecture and standards, integration of maintenance and logistics information systems, and required interfaces with operational systems.	
Processes	Integrate RCM; configuration management, a balance of reactive, preventive, and predictive maintenance actions; and CBM.	
Tools	Implement IETMs, AIT, and portable maintenance aids.	
Functionality	Ensure the capability to accomplish fault detection, isolation, prediction, reporting, assessment, analysis, decision-support execution and recovery, both on and off-board.	

This simple capability scorecard may be expanded, as required, to include specific milestone actions, responsible individuals and organizations, milestone dates, or other relevant information.

In addition to tracking milestone implementation through the capability scorecard, effective managers develop their own internal checklist to identify the key internal management elements that are essential for achieving progress in a large-scale management improvement initiative. Table 6-3 is an example of such a checklist, but it should be tailored to fit your particular circumstances.

Table 6-3. Internal Progress Evaluation Criteria

Progress element	Evaluation criteria
Management support	Statements of support Documented approval of projects Providing ideas/input Praise and publicity for successes
Team building/program initiation	Employee understanding of concepts Completed training Review policy and CBM$^+$ requirements Using skills from training Actively supporting projects Providing ideas and feedback
Understanding the process	Processes, systems, and resources requirements documented Architecture diagrams developed Applicable technologies identified Metrics system implemented

Table 6-3. Internal Progress Evaluation Criteria

Progress element	Evaluation criteria
Project implementation	Project milestones completed on schedule, within budget Cost savings measured and attained Process quality improved
Continuing the program	Follow-up and review procedures established Employees kept informed and involved; CBM$^+$ capabilities institutionalized

Operating Metrics—How to Measure a Maintenance Program Operating in a CBM$^+$ Environment

CBM$^+$ policy empowers the Services and PMs to pursue maintenance process improvement and technology to more effectively support the operational warfighter. Since CBM$^+$ spans the maintenance environment, it is difficult to assign a single metric to measure it. One of the key challenges at the DoD and Service level is to gauge and map how CBM$^+$ is progressing. A common end state is improved maintenance from the maintainer's perspective as well as the warfighter's. CBM$^+$ implementers should track a small number of metrics over the long term to assess whether CBM$^+$ improvements are enabling a more effective maintenance process. The Under Secretary of Defense (AT&L) has established policy for the selection of metrics applicable to logistics activities under the TLCSM concept.[1] The set of metrics directed by the Under Secretary provide an excellent focus for efforts to assess the results of a CBM$^+$ initiative.

Regardless of the suite of operating metrics chosen to help track the impacts of a CBM$^+$ implementation, the maintenance community must attempt some quantification of the effect of CBM$^+$ capabilities. In many cases the application of simulation and modeling techniques can be useful in quantifying the metrics baseline and projecting future trends. As discussed earlier, the magnitude of required investment in time and funding makes such analysis an important part of the CBM$^+$ effort.

Relevant Operating Metrics for CBM$^+$

At the highest level, there are four measurable objectives of a maintenance program:

- Materiel availability—maximizing readiness and availability of weapon systems and equipment
- Materiel reliability—improving reliability of weapon systems, equipment, and components
- Ownership costs—reducing life-cycle ownership costs
- Mean down time—reducing mean down time.

[1] Under Secretary of Defense (AT&L) Memorandum, "Total Life Cycle Systems Management Metrics," November 22, 2005.

These metrics are described in detail in Section 1. At a minimum, CBM^+ initiatives should be measured using these life-cycle sustainment metrics.

Maximizing Readiness and Availability

DoD policy states that the preferred metrics for measuring readiness and availability are operational availability and mission reliability. Each of these measures has a maintenance component that could be affected by CBM^+ improvements. Some related metrics include the following

- Mission capable rates-operational availability—currently reported quarterly in Quarterly Readiness Report to Congress (QRRC) (probably the best measure currently available);
- Readiness of equipment and supplies on hand—currently available as required through the Global Status of Resources and Training System (GSORTS); and
- Logistics response time, a measure of supportability and an indirect measure of readiness—available as required through an Office of the Secretary of Defense logistics response-time database.

Improving Reliability

Reliability is defined as the ability of a system to perform as designed in an operational environment over a prescribed period without failure. DoD's system reliability objective is to minimize the risk of failure within the defined availability, cost, schedule, weight, power, and volume constraints. As discussed earlier, materiel reliability is generally expressed in terms of a mean time between failures (MTBF). Once operational, it can be measured by dividing actual operating hours by the number of failures experienced during a specific interval.

Reducing Life Cycle Ownership Costs

DoD policy prefers the measure of life-cycle cost (LCC) to be total life-cycle cost per unit of usage. However, capturing total life-cycle logistics ownership costs continues to be a problem, as no credible measures are readily available to capture life-cycle costs across the Services on a timely and accurate basis.

Some potential cost metrics include the following:

- Cost per unit of operation—a pending TLCSM proposed metric that would be the best measure of life-cycle costs
- Weapon system program total operating cost
- Visibility and Management of Operating and Support Costs Program and other similar systems—attempt to capture life-cycle costs of weapon systems, but their accuracy and timeliness is viewed as unreliable
- Other internal Service cost systems that permit comparisons of cost of maintenance labor and parts over time.

Reducing Mean Down Time

MDT is the average total downtime required to restore an asset to its full operational capabilities. MDT includes the time from reporting of an asset being down to the asset being given back to operations/production to operate. The transition to more condition-based maintenance approaches should significantly reduce MDT by basing decisions to take weapons and equipment out of service on actual maintenance needs rather than time-based criteria.

Other Measures

Logistics footprint is defined as the presence of government or contractor logistics support required to deploy, sustain, or move a weapon system. Measurable elements include inventory/equipment, personnel, facilities, transportation assets, and real estate. Representative elements included in the quantification of logistics footprint include weight (e.g., total weight of deployable consumables, support equipment, energy and spares); personnel (e.g., total number of support personnel in the deployed area); and volume (total volume of deployable consumables, support equipment, energy and spares).

Due to the difficulty of obtaining timely and accurate metric data, the following measures could be used either as a supplement to or interim substitutes for the above metrics:

- Shorter maintenance cycles, including
  - Field-repair cycle times
  - Depot-repair cycle times
  - Shop-flow days.
- Increased quality of processes means fewer repeat repairs (may be detectable with serial item management tracking); reliability measures are similar to those listed under quality of product below.
- Increased quality of product, including
  - Field maintenance–related MTBF—currently not available, but a pending balanced scorecard (quarterly) and TLCSM (quarterly) metric
  - Depot maintenance–related MTBF—same as above
  - MDT—proposed TLCSM (quarterly)
  - Equipment availability—available quarterly through QRRC and as required through GSORTS.
- Number of repairs accomplished at field/intermediate level versus returns to depot for repair/overhaul.

Attachment A. CBM+ Technologies, Enabling Tools, and Best Practices

Table A-1 summarizes the approaches for selecting and using the technologies, tools, and best practices available to CBM+ implementers.

Table A-1. Technologies, Tools, and Practices Checklist

1.	Have we surveyed results and lessons learned by other organizations and the private sector before selecting new methods and technologies?
2.	Have we validated selected CBM+ technology applications in terms of their value in support of DoD, Service, and equipment program CBM+ objectives?
3.	Have we developed a phased CBM+ implementation plan that ensures most effective application of new methods and technologies?
4.	Are our CBM+ technologies and selected applications based on a credible business case analysis?
5.	Does our CBM+ implementation approach incorporate appropriate best business practices for implementing new methods and technologies?
6.	Have we matched selected new methods and technologies with the human components of the CBM+ initiative through effective familiarization and training efforts?
7.	In the end, will our CBM+ initiative help promote accomplishing maintenance tasks only when needed?

CBM+ expands on basic CBM concepts, encompassing other technologies, processes, and procedures that enable improved maintenance and logistics practices. A variety of advanced engineering, maintenance, and information system technologies, coupled with contemporary business processes, underpin CBM+. Ultimately, a successful CBM+ implementation must rely upon a combination of hardware and software tools employed judiciously to produce an integrated information system. This attachment summarizes a representative range of the technologies, tools and best practices available to a CBM+ implementation team.

Technologies and Enabling Tools

CBM+ includes, but is in no way limited to, hardware and enabling tools and software.

Hardware and Enabling Tools

The key hardware components of a CBM+ application include embedded and off-system sensors that record and monitor equipment operating parameters; portable maintenance aids (PMAs) with interactive electronic technical manuals (IETMs) that facilitate troubleshooting and repair actions, and network communication equipment that enable remote analysis.

The "plus" in the CBM+ strategy expands condition based maintenance to include related maintenance technologies and processes not necessarily included in current maintenance programs. Some of the most prominent enabling tools include serial item management (SIM) and automated information technologies that facilitate maintenance data collection. The distinction between CBM+ hardware and enabling technologies is somewhat subjective, and some categorize PMAs as enabling tools:

- Sensors provide the raw data for both diagnostic and prognostics purposes. Usually they are embedded in equipment platforms but may be off-system in some cases. Sensors are commonly used to measure operating parameters, such as current, voltage, temperature, pressure, vibration, pathway flows, fuel and ammunition levels, operating status, and time-based usage.

- PMAs are replacing paper-based technical data and making it easier to use. These include digitized technical manuals, particularly in Class V IETMs that can utilize health monitoring information to walk maintenance technicians step-by-step through equipment troubleshooting and repair processes. Links to technical drawings, parts lists, and maintenance training materials can be incorporated into IETMs so that maintenance technicians can easily access maintenance aids during maintenance processes.

- Network communication equipment that transmits Health and Usage Monitoring System (HUMS) information to remote locations include radio, satellite, and Wi-Fi (i.e., wireless fidelity local area networks). The principal means for platform over-the-horizon communications is FM radio and satellite. Wi-Fi typically offers greater bandwidth, and therefore is more expedient for transmitting equipment raw sensor health data off the equipment. However, its transmission distance is very limited, usually a few miles at most.

- SIM of equipment and their components enable more detailed configuration management and improved materiel asset tracking. The Under Secretary of Defense for Acquisition, Technology and Logistics instituted the Unique Identification (UID) Program to expand the use of serial item management across the Department. The UID Program will enable easier and more accurate access to information about DoD property that will make acquisition, repair, and deployment of items faster and more efficient.

- Automatic identification technologies, such as radio frequency identification (RFID) devices and 2D matrix devices, can assist in troubleshooting and identifying low-reliability components by providing visibility into maintenance histories of individual equipment components. RFID technologies allow storage of maintenance histories directly on the equipment components. Other RFID tags store serial numbers to enable maintenance histories to be stored and tracked in databases off the equipment platforms. DoD is also expanding the use of RFID and other technologies for asset tracking purposes to increase materiel visibility and accountability of end items and components both within and outside the maintenance process.

Software

The CBM+ information technology infrastructure includes the diagnostic and prognostic software that enable decision support and analysis capabilities. The software can be divided into two main categories: equipment software and enterprise software. The goal of equipment software is primarily to enable real-time embedded system health management and to collect data for subsequent use in enterprise data repositories. The goal of enterprise software is to provide business intelligence and decision support. Enterprise software often includes software applications similar to those found at the equipment level, but may include data repositories and the applications that use information from the databases generated by equipment software.

Equipment software may be on-system, i.e., embedded on the equipment, or at-system, e.g., use a portable computer that runs many of the same applications that might otherwise be on-equipment. Examples of platform-related health monitoring software applications may include

- configuration management data and applications,
- operating history data collection and storage,
- digital logbooks, an automated event recording system
- message managers (a process for network management of event-driven messages),
- Health Data Storage System (a data base management system for asset health management data),
- diagnostic applications for analyzing causes of failures,
- predictive maintenance forecasting (single or multiple correlated sensor data trend analysis),
- prognostic forecasting (a system that uses model-based reasoning and analysis of correlated sensor and measurement data to predict equipment/component remaining life), and
- interactive electronic technical manuals and interactive training.

Enterprise-level software can be used to increase the usefulness of CBM+ information at the enterprise level. For example, by aggregating and analyzing data from multiple platforms, predictive maintenance can be performed for an equipment fleet or geographic region. Enterprise software may also include logistics information systems that manage supply, maintenance and distribution, and the command and control systems. Some primary enterprise-level software applications include

- message managers,
- data archives (i.e., a CBM+ data warehouse),

- communication software, and
- health management software (includes business intelligence applications that extract information from a data warehouse for predictive maintenance analysis of individual components, equipment, or groupings of equipment).

Current CBM$^+$ Technology Trends

Some of the technology advances that are increasing the rapidity of assessment of machinery condition and providing the technological foundation for CBM$^+$ include

- miniaturization of sensors,
- development of sensors that enable monitoring of debris in lubricating oils and the condition of oils themselves,
- sensors that enable the detection severity of hidden corrosion and general corrosiveness of environments and acoustic and vibrational measures,
- life-prediction methodologies and real-time computations,
- signal processing and multi-sensor data fusion, and
- intelligent reasoning and control.

Despite these improvements, implementers face major challenges in the practical implementation of CBM$^+$ technologies and operational applicability in DoD. Those challenges include the following:

- The development and integration of self-powered or power-harvesting wireless microsensors capable of operating in high thermal or high mechanical load environments.
- Improved models and methodologies that can predict health and expected life based on physical, mechanical, or other measurements.
- Reliable methods to measure and predict corrosion degradation in unstable environments.
- Predictive tools for advanced materials, materials systems, and structures and design concepts for in-service monitoring.
- Design tools to assist in selecting the most appropriate monitoring approach for a specific mechanical or electrical/electronic system.

Best Way to Apply Technologies

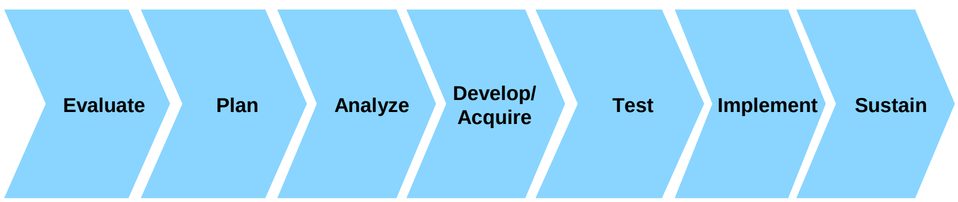
Technologies should be applied in a CBM$^+$ initiative when and where they help achieve program goals and make economic sense. A successful technology project can only be the result of solid management, committed team members, and a clearly defined implementation approach.

A well-planned and executed CBM^+ technology implementation should

- align applications with established goals and objectives,
- define the project's critical path,
- include the right people skills, and
- ensure milestones and deliverables are met on time and within budget.

CBM^+ implementations should be conducted in phases. These technology-focused phases correspond with the overall implementation strategy described in Section 4. Each technology application phase should have specific objectives and deliverables that contribute to the overall success of the project. Since these phases build upon one another, it is important to complete the necessary activities in one phase before moving on to the next. Figure A-1 shows a structured approach to technology implementation.

Figure A-1. Structured Approach to Technology Implementation



By applying this type of phased approach to technology implementation, implementers can be more confident in the ultimate success of their CBM^+ initiative.

Best Practices

In addition to selecting the most productive set of implementing technologies, another important factor to consider when developing a CBM^+ strategy is the adoption of best practices to improve the process and make best use of the technology enablers.

Design

- Incorporate open system architecture when designing hardware, software and business processes, to achieve maximum interoperability, portability, and scalability.
- Apply government and industry standards, including those listed in Section 3 of this Guidebook, to help achieve open systems architecture. When designing data exchange and storage strategies, apply MIMOSA Open Systems Architecture for Enterprise Application Integration (OSA EAI) when possible.
- Use commercial off-the-shelf (COTS) applications to facilitate the sharing of data and to promote the integration of maintenance and logistics information systems.

- Design weapon systems to use measurable, consistent, and accurate predictive parameters related to specific failure modes when cost analysis determines embedded CBM^+ should be employed.
- Use automatic entry and retrieval to achieve more accurate data.
- Integrate data from different sources to achieve to achieve integrated condition monitoring and analysis capability.
- Utilize a holistic approach of equipment condition monitoring to ensure accurate and timely condition monitoring results.
- Utilize shared databases to maximize the benefit of condition-based maintenance data.
- Design an integrated infrastructure of hardware and software.
- Design prognostic analytics with the flexibility to accept many different sources of data to make accurate predictions of useful life.
- Develop an integrated CBM^+ architecture early in the implementation process. Consider using the DoD Architectural Framework (DoDAF) for that purpose.

Functionality

- Design fault detection, fault isolation, and fault prediction capabilities with low ambiguity to ensure that capabilities are sufficient to meet health monitoring and predictive requirements.
- utilize built-in-test (BIT) and off-equipment PMAs to achieve the desired functionality.
- Maximize the use of predictive maintenance strategies and implementation of CBM^+ enablers To improve failure prediction capabilities.
- Consider developing and applying expert system software to achieve better and more accurate condition-based monitoring.
- Integrate maintenance and other functional logistics information systems across the enterprise to obtain the maximum benefit from a CBM^+ strategy.

Processes

- Perform a business case analysis to determine where applications of CBM^+ make economic sense. Often a reliability centered maintenance approach can serve this purpose, as well as provide the economic basis for striking a balance among reactive, preventive, and predictive maintenance processes.
- Use reliability analysis to determine optimum maintenance task functionality, which failure modes are consequential, and the most economical CBM^+ applications.

- Fully utilize condition monitoring analysis information when evaluating potential investments in reliability improvements or changes in equipment maintenance approaches.
- Invest prudently in sensor, data collection, and analytic capabilities to minimize condition monitoring and failure analysis errors.
- Develop and use metrics driven by condition-based maintenance information to enhance equipment performance assessments.
- Follow Life Cycle Management guidelines when applying CBM+ throughout the equipment acquisition process.
- Consider using modeling and simulation in CBM+ to determine the most economical design approaches.

Attachment B.
Resources and References

The DoD CBM$^+$ website serves as the clearinghouse for CBM$^+$ information and presentations; cross-Service policy documents; links to government, academia, and industry Web sites; and upcoming events. The CBM$^+$ web address is http://www.acq.osd.mil/log/mppr/CBM%2B.htm.

DoD CBM$^+$ Policy

DoD Directive 5000.1, *The Defense Acquisition System*, May 12, 2003, http://www.dtic.mil/whs/directives/corres/pdf/500001_051203/500001p.pdf.

DoD Instruction 5000.2, *Operation of the Defense Acquisition System*, May 12, 2003, http://www.dtic.mil/whs/directives/corres/pdf/i50002_051203/i50002p.pdf.

DoD Directive 4151.18, *Maintenance of Military Materiel*, May 3, 2004, http://www.acq.osd.mil/log/mppr/general_policy/4151_18_march04.pdf.

DoD Instruction 4151.19, *Serialized Item Management* (SIM) *for Materiel Maintenance*, December 26, 2006, http://www.acq.osd.mil/log/mrmp/415119p.pdf.

DoD Instruction 4151.22, *Condition Based Maintenance Plus* (CBM$^+$) *for Materiel Maintenance*, December 2, 2007, http://www.acq.osd.mil/log/mrmp/cbm+/docs/DoDI_415122.pdf.

Under Secretary of Defense (AT&L) Memorandum, "Total Life Cycle Systems Management Metrics," November 22, 2005. https://acc.dau.mil/CommunityBrowser.aspx?id=32594.

Under Secretary of Defense (AT&L), *Strategic Goals Implementation Plan for FY2007*, November 2006, http://www.dau.mil/Spotlight/ATL%20Implementation%20Plan.pdf.

CBM$^+$ Acquisition Community Connection website https://acc.dau.mil/CommunityBrowser.aspx?id=32444.

Designing and Assessing Supportability in DoD Weapon Systems: A Guide to Increased Reliability and Reduced Logistics Footprint" October 24, 2003, available at https://acc.dau.mil/CommunityBrowser.aspx?id=32566.

Military Services CBM+ Policy Documents

Army

Assistant Secretary of the Army (ALT) Memorandum, "Condition Based Maintenance Plus - CBM+, March 20, 2008, http://www.acq.osd.mil/log/mrmp/cbm+/Army/CBM+.pdf.

AR 750-01, *Army Materiel Maintenance Policy*, September 20, 2007, http://www.army.mil/usapa/epubs/750_Series_Collection_1.html.

Navy

Chief of Naval Operations (OPNAV) Instruction 4790.16, *Condition Based Maintenance* (CBM) *Policy*, December 17, 2007, http://www.acq.osd.mil/log/mrmp/cbm+/Navy/OPNAVINST4790.16A.pdf.

Assistant Secretary of the Navy (RD&A) Memorandum, "Condition Based Maintenance Plus Policy," January 2003, http://www.acq.osd.mil/log/mppr/cbm%2B/Navy/ASNRDAendorsement.PDF.

Air Force

Air Force Instruction 63-107, *Integrated Product Support Planning and Assessment*, November 2004, http://www.e-publishing.af.mil/pubfiles/af/63/afi63-107/afi63-107.pdf.

U.S. Air Force Condition Based Maintenance Plus Initiative http://www.acq.osd.mil/log/mppr/cbm%2B/Air_Force/AFLMA%20CBM%20final%20Sep%2003.pdf.

Marine Corps

Commandant of the Marine Corps, Headquarters Marine Corps Order 4000.57, *Marine Corps Total Life Cycle Management*, September 2005, http://www.marines.mil/news/publications/Pages/order_ssic_04.aspx.

Procedural References

DoD Continuous Process Improvement Transformation Guidebook, https://acc.dau.mil/CommunityBrowser.aspx?id=32364.

DoD Acquisition Guidebook, http://akss.dau.mil/dag/.

Performance Based Logistics: A Program Manager's Product Support Guide, March 2005, https://acc.dau.mil/CommunityBrowser.aspx?id=32536.

DoD Reliability and Maintainability Guide, August 3, 2005, https://acc.dau.mil/CommunityBrowser.aspx?id=22534.

Other References Academia

Christianson, LTG C.V., Director, Joint Logistics, JCS," Joint Logistics–Shaping Our Future, *A Personal Perspective,"* Defense AT&L Magazine, July–August 2006.

Moubray, John, *Reliability-Centered Maintenance II*, Second Edition, Industrial Press, Inc., 1997.

Nowlan F. Stanley. and Heap, Howard F., *Reliability Centered Maintenance*, DoD Report A066-579, December 29, 1978.

Mobley, Keith R., *An Introduction to Predictive Maintenance*, 2 Ed,. Butterworth-Heinemenn, 2002.

Cutter, David and Owen Thompson, *Condition-Based Maintenance Plus Select Program Survey*, LMI Report LG301T6, January 2005.

CBM+-Related Standards

Standards referenced in this Guide and related standards can be obtained at the following sites.

International Organization for Standardization, http://www.iso.org/iso/en/ISOOnline.frontpage.

Society of Automotive Engineers International, http://www.sae.org.

Institute of Electronics and Electrical Engineers, http://www.ieee.org.

Machinery Information Management Open Systems Alliance, http://www.mimosa.org.

ASSIST-Online, http://assist.daps.dla.mil/online/start/.

Department of Defense Architecture Framework, http://www.defenselink.mil/cio-nii/docs/DoDAF_Volume_I.pdf.

DISR, https://disronline.disa.mil/

Defense Architecture Registry System, https://dars1.army.mil/IER/index.jsp.

DoD Technology Related Reference Sites

The following websites are a source for DoD-sponsored topics and initiatives for additional technical information.

Defense Acquisition University, https://acc.dau.mil/CommunityBrowser.aspx.

Defense Advanced Research Projects Agency, http://www.darpa.mil/.

Defense Technical Information Center, http://stinet.dtic.mil/index.html.

Reliability Information Analysis Center, http://quanterion.com/RIAC/index.asp.

Army Research Laboratory, http://www.arl.army.mil/main/Main/default.htm.

Navy Research Laboratory, http://www.nrl.navy.mil.

Air Force Research Laboratory, http://www.afrl.af.mil.

DoD Small Business Innovative Research and Technology Transfer, http://www.acq.osd.mil/osbp/sbir/.

DoD Tech-Match, http://www.dodtechmatch.com/DOD/index.aspx.

Attachment C.
CBM$^+$ Implementation Plan Template

Purpose

The purpose of this template is to provide program managers (PMs), their staff, and logistics participants in the program life-cycle process an implementation plan tool to assist them in ensuring that effective sustainment is addressed and accomplished through the application of a CBM$^+$ strategy.

Implementation plans vary widely in scope, format, and level of detail. Implementers should use the format that best meets their needs, but bear in mind the requirement for credibility and ease of understanding by all potential readers.

The CBM$^+$ implementation plan may differ from the format suggested below; however, a formal implementation plan must be prepared, fully staffed, and approved by appropriate levels of management before initiating further implementation actions. After management approval, the plan should be "sold" to major process customers and stakeholders. After initial approval, the plan will be expanded into greater levels of detail and include contracting approaches, particularly as the CBM$^+$ architectural documentation is completed.

It is important the CBM$^+$ implementation plan be kept current and aligned with management decisions, resource availability, acquisition of essential CBM$^+$ elements, and attainment of milestones. Often changes outside the control of the maintenance organization will affect the CBM$^+$ implementation schedule. These fact-of-life conditions are common. By revising the implementation plan to accommodate such changes, the focus and credibility of the team will be maintained. Often, scaling back the scope of implementation or extending implementation target dates will be necessary. A flexible manager will use such setbacks to fine-tune planning or even chart alternate implementation strategies.

The following outline is a starting format for a CBM$^+$ plan.

Outline

1. Scope

Prepare a comprehensive statement that covers the planned scope of the CBM$^+$ application, including equipments, organizations, and functions.

2. Objectives

Outline the general supportability objectives (including outcome-related goals and objectives) for the major maintenance activities to be covered.

3. Alternative Description

Describe how initiative goals and objectives—and the personnel, capital, information management, and funding resources required to meet those goals and objectives—are to be achieved, including a general description of the analysis of alternatives that lead to required operational and analytic processes, skills, and technologies.

4. Requirements Statements and Planned Design

Outline the requirements statements and planned design approaches for each of the six CBM^+ essential elements described below. (See Section 3, of this Guidebook for additional detailed discussion and explanation)

CBM^+ elements can be categorized into two primary categories—business/management and technical—and six subgroups within these two categories. All the CBM^+ elements contribute to the development of the maintenance plan across the entire life cycle of the weapon system or platform.

4.1 Business Management

4.1.1 Policy and doctrine: Review the guidance from senior DoD and Service management covering the requirement to implement the CBM^+ strategy, and incorporate the guidance into the objectives and benefits of the effort, along with who is responsible, and the target end state.

4.1.2 Business strategy: Identify the business needs for improving the assessment and satisfaction of the maintenance requirements that drive the need for CBM^+, and incorporate the needs into the approach to accomplishing the CBM^+ business case. DAU has a continuous learning module on business case analysis (CLL015).

4.1.3 Relationship of CBM^+ to Reliability Centered Maintenance (RCM): Identify and implement the interactive relationship between RCM, as the defining process for determining the most effective maintenance strategies, and CBM^+, as the source of methods and technologies to execute the selected maintenance approaches.

4.2 Technical

4.2.1 CBM^+ infrastructure: Identify and acquire the hardware, software, and human interface components of the CBM^+ strategy. Relate these components to the infrastructure as the physical building blocks that must be available to CBM^+ implementers to construct an operational CBM^+ approach to condition based maintenance.

4.2.2 DoD Architectural Framework (DoDAF) **for CBM^+**: Briefly outline a high-level architectural overview that covers the scope of the CBM^+ initiative. Use the DoD standard methodology for building and using a structured design for describing the components and interfaces of the overall CBM^+ strategy. The architecture provides a holistic tool for constructing a comprehensive picture of the entire CBM^+ strategy.

4.2.3 Open systems and data strategy: Define the technical capabilities and procedures available to CBM^+ implementers to accomplish the most effective integration of hardware and software, and data management components of a CBM^+ strategy. These involve the use of existing commercial and government standards to facilitate interfaces among hardware data collection and storage devices, analytical and communications software, and condition-monitoring data repositories.

5. Key External Factors

Identify the key factors external to the organization and beyond the organization's control that could significantly affect achievement of general goals and objectives. The following external factors or potential obstacles[1] are provided as examples but should be used only as a starting point for each project:

- The "color of money" and the timeliness of funding
- Program funding reductions and out-year funding reliability
- Standards or lack of standards
- Technology maturity
- Legacy information technology processes
- Compatibility of new CBM^+ technologies with existing fielded systems.

6. Program Evaluation Process

Provide a description of the program evaluation process, including planned metrics, to be used in managing and evaluating progress toward achieving the desired levels of readiness and supportability within planned budget. See Section 6 of this Guidebook for additional information.

Identify performance measures (metrics) that will give managers and customers a consistent and quantifiable picture of maintenance performance and related costs.

Performance measures are categorized into implementation metrics and operating metrics.

6.1 Implementation Metrics

To help quantify progress toward a successful implementation, a balanced scorecard approach should be considered:

6.1.1. Meeting the strategic need of the enterprise.

6.1.2. Meeting the needs of the individual customer.

[1] LMI, *Condition-Based Maintenance Plus Select Program Survey*, David M. Cutter and Owen R. Thompson, Report LG301T6, January 2005.

6.1.3. Addressing internal business performance.

6.1.4. Addressing process improvement initiative results.

6.2 Operating Metrics

6.2.1. Material Availability: Identify the weapon system operational availability objectives.

6.2.2. Materiel Reliability: Identify the mean time between failure objectives for the weapon system, equipment, and components.

6.2.3. Ownership Costs: Identify cost per unit and total life-cycle operating costs.

6.2.4. Mean Down Time: Identify downtime to restore asset to full operational capability.

7. Plan of Action and Milestones

A plan of action and milestones outline is provided below.

7.1 Cover Sheet

Include title of the program, date, and organization.

7.2 Paragraph 1—Introduction

State the background of the program, its focus, its end state, and any policies and initiatives related to the program.

7.3 Paragraph 2—Organization

Reference the program's charter, and who monitors the program within the chain of command. Outline the organization structure, such as action groups and working integrated product teams.

7.4 Paragraph 3—Implementation Actions

Outline the actions that must be accomplished within a specific timeframe or period.

7.5 Paragraph 4—Milestones

Outline the steps on *how* the program will be achieved (e.g., revise policies, establish organizations, monitor or advise).

7.6 Paragraph 5—Membership

List the current members of the group responsible for the program.

Attachment D.
Overcoming the Resistance to Change

One of the main challenges of change initiatives like CBM$^+$ relates to the resistance that is often found in an organization. Overcoming that resistance is critical, but to do so implementers first understand it.[1]

What Is Resistance?

According to the Webster's New Collegiate Dictionary, resistance is an opposing or retarding force. In dealing with change efforts to implement CBM$^+$, maintenance managers should understand that individual resistance to change in a work environment stems from at least four different things.

Type 1 Resistance—Lack of Context and Direction

Type 1 Resistance stems from employees not understanding the objectives, benefits, and future vision of the organization. This situation may arise in organizations where internal communications operate on a non-participative or one-directional basis, and are for the most part unplanned. When context and directional understanding is maximized, resistance of this sort declines significantly.

DoD example: CBM$^+$ implementation must be well understood in order to be supported by stakeholders, managers, maintainers, and customers. One purpose of this Guidebook is to promote such understanding.

Type 2 Resistance—Emotional Reaction

Emotional resistance stems from fear of the change being proposed or implemented. People's fears are driven by a lack of understanding of multiple issues, including not knowing how their jobs will be impacted, loss of organizational workload and restructuring, and implementation of new business processes and technologies. Helping them understand what is happening, when and how change will occur, and what plans are in place during and after the change will do much to help overcome emotional resistance. Managers need to understand that until they deal with emotional resistance, it will be nearly impossible to address context and directional resistance.

DoD example: People and organizations like to believe they are "different;" what applies to others won't work here!

[1] The material in this appendix is based on information from Strategic Connections Inc; see http://www.strategicconnections.com/info_articles.htm.

Type 3 Resistance—Trust

Effective change relies heavily on the level of trust that exists among employees, their supervisors or managers, and the organization itself. Where trust is low (based on past experience), resistance will be high. When trust is high, efforts to advance change become much easier.

DoD example: DoD organizations have a long history of "failed" initiatives particularly in the area of implementing information technology, which sometimes makes it difficult to engender confidence in new initiatives.

Type 4 Resistance—Personality Clashes Between Employees and Management

DoD has not given much thought to this type of resistance as the military "chain-of-command" culture usually precludes open resistance to change even among civilian or contractor employees. However, the phenomenon of "passive" resistance has sometimes been acknowledged by senior DoD and Service officials. Essentially this resistance means that many employees or organizations may not actively follow the new direction set by the management simply because they did not like those responsible for leading the way. (Focus group participants have suggested that the changes being proposed may be the right thing to do, but supporting them does not occur because some members of the management team were not necessarily liked or respected.) This type of resistance is actually quite common and needs to be monitored and addressed to keep the change on track and sustainable.

DoD example: Actual overt personality clashes are rare in DoD organizations. However, a variance of this type of resistance occurs based on such factors as real or perceived conflicting direction from multiple layers of management, communications breakdowns, failure to follow through on planned actions or programs, frequent changes of direction, and rapid turnover of political and military leadership

Overcoming Resistance

Managers should understand that resistance may take numerous forms. This is the first step in overcoming it. Table D-1 summarizes some of the actions that may assist in addressing each type of resistance.

Table D-1. Actions to Overcome Resistance

Type of resistance	Potential actions
Lack of context and direction	◆ Presentations on initiatives/training ◆ Employee forums ◆ Newsletters ◆ Published planning documents
Emotional reaction	◆ Acknowledgment of fears ◆ Face-to-face communications—manager/supervisor with employee—formal and informal ◆ Presentation of facts on change activity ◆ Continuous two-way dialogue ◆ Team participation
Trust	◆ Relationship building ◆ Planned communication ◆ Follow-through on planned actions ◆ Active listening ◆ Openness and honesty
Personality clashes (otherwise known as “passive resistance”)	◆ Coordinated and consistent management direction ◆ Scale scope of initiatives to credible/achievable levels ◆ Clear, concise, and consistent guidance ◆ Well-documented policies and procedures ◆ Effective and relevant training ◆ Employee feedback mechanisms. ◆ Adherence to established objectives and targets whenever possible

Attachment E. Abbreviations

AIT	automatic identification technology
ASSIST	Acquisition and Streamlining Standardization System
BCA	business case analysis
CBM^+	Condition Based Maintenance Plus
CJCSM	Chairman Joint Chiefs of Staff Manual
COTS	commercial off-the-shelf
CPI	Continuous Process Improvement
CSDB	Common Source Data Base
DAG	Defense Acquisition Guidebook
DISR	Department of Defense Information Technology Standards Registry
DoDAF	Department of Defense Architectural Framework
EAI	Enterprise Application Integration
FL	Focused Logistics
GSORTS	Global Status of Resources and Training System
IEEE	Institute of Electronics and Electrical Engineers
IETM	integrated electronic technical manual
IPT	integrated product/process team
ISO	International Organization for Standardization
IT	information technology
JCIDS	Joint Capabilities Integration and Development System
KPP	key performance parameter
KSA	key system attribute

LCC	Life-cycle cost
MA	materiel availability
MDT	mean down time
MIMOSA	Machinery Information Management Open Systems Alliance
MTBF	mean time between failure
O&S	operations and support
OC	ownership cost
OSA	open systems architecture
OSD	Office of the Secretary of Defense
OV	operational view
PBL	Performance Based Logistics
PDCA	Plan, Do, Check, and Act
PM	program manager
PMA	portable maintenance aid
PPBS	Planning, Programming, and Budget System
QRRC	Quarterly Readiness Report to Congress
RCM	Reliability Centered Maintenance
S&RL	Sense and Respond Logistics
SAE	Society of Automotive Engineers
SV	systems view
TLCSM	Total Life Cycle System Management
TV	technical standards views
USD (AT&L)	Under Secretary of Defense for Acquisition, Technology and Logistics

V&V	validation and verification
VAMOSC	Visibility and Management of Operating and Support Costs