Condition-Based Maintenance Plus Guidebook

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Condition-Based Maintenance Plus Guidebook

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Condition-Based Maintenance Plus Guidebook Change Record

Date	Change	Rationale
August 2024	Initial Version	

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1. Introduction

1.1. Guidebook Objectives

This guidebook is meant to provide the user with information on the origination of CBM+, the intent of CBM+, the necessary elements for implementing and sustaining a CBM+ instance, and examples of the tools and best practices from across the department. This guidebook is meant to further explain and clarify the relationship and necessary elements defined in DoDM 4151.25, Reliability-Centered Maintenance and DoDI 4151.22, Condition-Based Maintenance.

No guidebook can ever be complete therefore this is just one tool to be used in conjunction with other available resources. Examples of those resources include the CBM+ Working Group, the Joint Technology Working Group (JTEG), the DoD Maintenance Symposium, DAU training opportunities, Service-led training opportunities and other Service-specific forums made available to all CBM+ practitioners.

1.2. Condition-Based Maintenance Plus Overview

1.2.1. What is CBM+?

CBM$^+$ is the proactive maintenance strategy developed within the Department of Defense to achieve cost-effective weapon system life-cycle sustainment. DoD Instruction 4151.22 defines CBM$^+$ as:

> *"A collaborative DoD readiness initiative focused on the development and implementation of data analysis and sustainment technology capabilities to improve weapon system availability and achieve optimum costs across the enterprise. CBM+ is the application and integration of 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.*
>
> *CBM+ is built upon RCM and condition-based maintenance to enhance safety, increase maintenance efficiency, improve availability, and ensure environmental integrity.*
>
> *CBM+ diminishes life-cycle costs by reducing unscheduled maintenance and enabling predictive maintenance.*

> *CBM+ turns rich data into information about component, weapon system, and fleet conditions to more accurately forecast maintenance requirements and future weapon system readiness to drive process cost efficiencies and enterprise activity outcomes*”[1]

CBM+ encompasses an architecture that enhances the principles of RCM and CBM by incorporating enablers, tools, and technologies, that increase maintenance effectiveness and improve materiel availability and operational readiness. CBM+ uses a systems-engineering approach to collect data, enable analysis, and support the decision-making processes for system acquisition, sustainment, and operations. CBM+ facilitates the development of the appropriate maintenance strategies and maintenance plans utilizing all levels of maintenance found along the maintenance continuum, Figure 1, ultimately improving operational effectiveness.

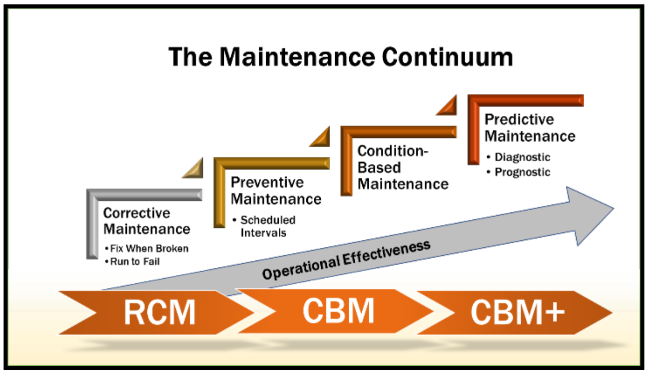

Figure 1 - The Maintenance Continuum

1.2.2. Why Change?

The sustainment aspects of a weapon system’s life cycle are key to ensuring their availability and readiness in support of our National Defense Strategies. Innovation is the cornerstone of how we will provide better, cheaper, faster, more precise, and safer sustainment and readiness of DoD weapon systems.

The life-cycle impact is clear when operations and support (O&S) costs are compared to total ownership costs, as shown in Figure 2.

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[1] DoDI 4151.22, *Conditioned Based Maintenance Plus (CBM+) for Materiel Maintenance, 14 August 2020*

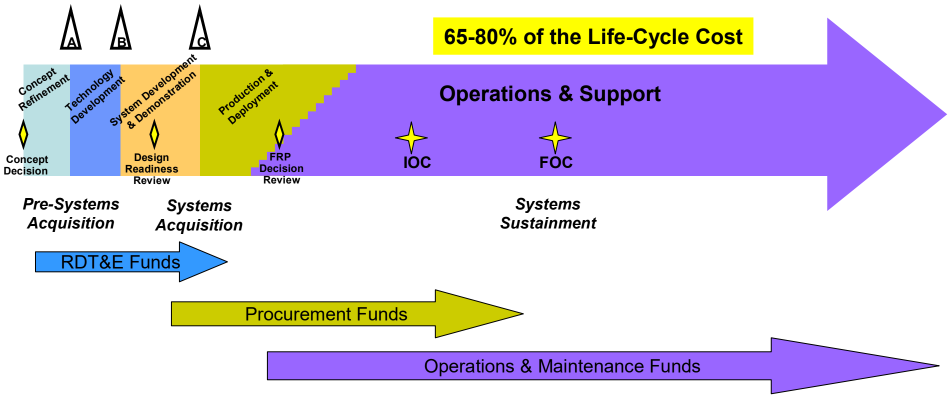

Figure 2 - Life Cycle Costs

DoD has identified warfighter expectations and seeks to conduct support operations in a more effective as well as fiscally responsible manner. Under the umbrella of Product Support (PS), the sustainment of a weapon system receives increased attention from Service leadership and program managers. A Product Support Strategy (PSS) 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 PS 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 3 displays the relationship of these tools to the PSS.

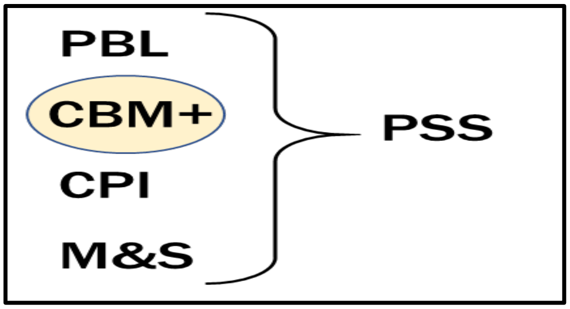

Figure 3 - Product Support Strategy

CBM+ supports the larger DoD improvement efforts of the Under Secretary of Defense for Acquisition and Sustainment (USD[A&S]), with the goal of delivering cost-effective joint logistics performance by maximizing weapon system and equipment availability through more effective logistics processes. The strategy fully supports these broad, long-term goals articulated in the A&S Strategy Roadmap:[2]

- Enable innovative acquisition approaches that deliver warfighting capability at the speed of relevance.
- Build a safe, secure, and resilient Defense Industrial Base (commercial and organic).
- Ensure safe and resilient DoD installations.
- Increase weapon system Mission Capability while reducing operating cost.
- Promote Acquisition & Sustainment initiatives with key international partners.
- Recruit, develop, and retain a diverse Acquisition & Sustainment workforce.
- Capable, efficient, and cost-effective installations.

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

- engage early-on in the acquisition process to identify and incorporate CBM+ enabling technologies into new weapon systems;
- evaluate fielded weapons systems for opportunities to inject CBM+ enabling technologies when supported by life-cycle readiness and cost analyses;

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[2] USD(A&S), *Strategy Roadmap*, April 2020.

- enhance materiel availability at the best possible cost by establishing integrated, predictive maintenance approaches that minimize unscheduled repairs;
- eliminate unnecessary maintenance activity;
- employ the most cost-effective maintenance health management approaches and;
- integrate with supply chain operations to deliver the right parts to the right place at the right time.

To meet these challenges, DoD management, as well as Congressional leaders, are paying specific attention to the implementation and operationalizing of CBM+ into DoD weapon systems and equipment, and the execution of CBM+ across the Services during the sustainment life cycle.

1.2.3. 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 the tenets of reliability-centered maintenance (RCM) and condition-based maintenance (CBM). It encompasses other technologies, processes, and procedures that enable improved maintenance and logistics practices.[3]

CBM is defined as 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 build 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

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

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 optimizes requirements for maintenance manpower, facilities, equipment, and other maintenance resources.

CBM+ is not a single 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 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 maintenance planning and execution. At its core, CBM+ is maintenance performed upon evidence of need provided by RCM analyses 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 4.

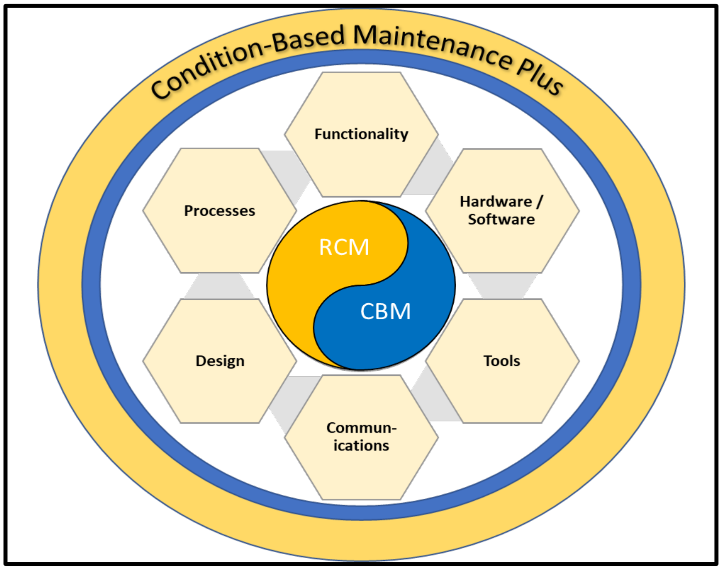

Figure 4 - CBM+

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

- *Hardware / Software*—system health monitoring and management using embedded sensors; integrated data buses; decision support and analysis capabilities both on and off equipment; appropriate use of diagnostics and prognostics; automated maintenance information generation and retrieval.
- *Tools*—integrated electronic technical manuals (IETMS) (i.e., digitized data); automatic identification technology (AIT); item-unique identification (IUID); portable maintenance aids (PMAs); embedded, data-based, interactive training.
- *Communications*—databases; off-board interactive communication links.
- *Design*—open system architectures; integration of maintenance and logistics information systems; interfaces with operational systems; designing systems that require minimum maintenance; enabling maintenance decisions based on equipment condition.
- *Processes*—RCM analyses; 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.
- *Functionality*—low ambiguity fault detection, isolation, and prediction; optimized maintenance requirements and reduced logistics support footprints; configuration management and asset visibility.

1.2.4. Achieving More Effective Maintenance

To satisfy the requirements of a changing National Defense Strategy, maintenance managers are challenged to apply CPI[4] 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.

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

More effective maintenance requires a change in the culture of the maintenance community from a primarily reactive maintenance philosophy to a predictive and proactive, planned maintenance philosophy. This shift moves us from an environment primarily consisting of unscheduled maintenance to one where scheduled maintenance is the dominant element and is managed to support operational requirements (see figure 5). 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.

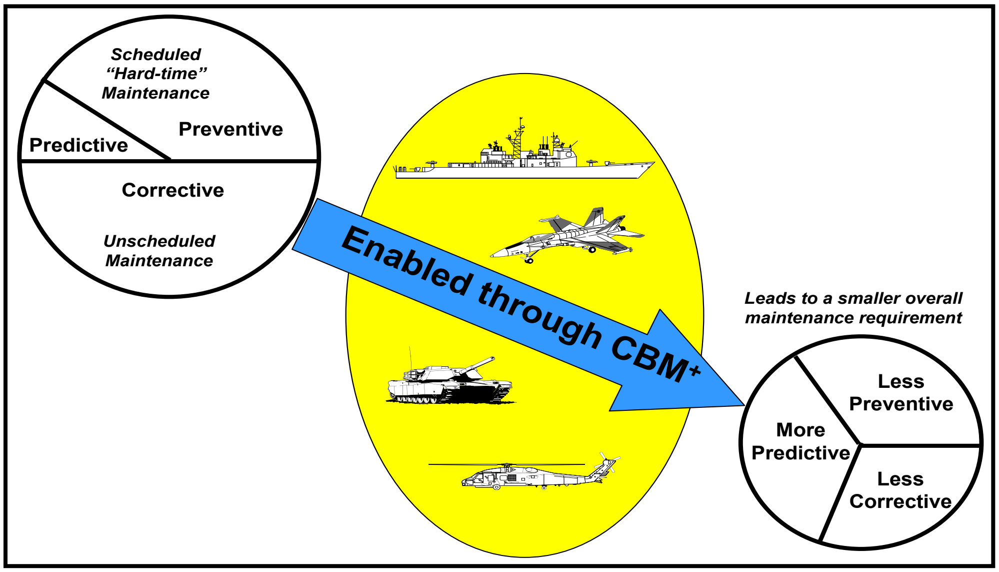

Figure 5 - Maintenance Transition

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.

1.2.5. 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 PSS concept, the sustainability and energy key performance parameters (KPPs) are critical to a program's success. The KPP metrics and supporting key system attributes (KSAs) are defined as follows:

- Sustainment KPP. This KPP is supported by elements that provide an integrated structure to balance sustainability with capability and affordability across the life cycle. The two elements of the sustainment KPP are Materiel Availability and Operational Availability.
    - Materiel availability (Am) 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.
    - Operational Availability (Ao) is a measure of the percentage of time that a system or group of systems within a unit are operationally capable of performing an assigned mission. This value can be expressed as uptime divided by the sum of uptime and downtime (uptime / uptime + downtime).
- Energy KPP. Energy performance (EP) is a key component of system and unit performance and relates to the required energy consumption needed to perform functions or tasks in operational modes, mission profiles and durations, and environmental conditions. Demands for fuel and electric power in capability solutions will be optimized, because they directly affect the demand on the force to provide and protect critical energy supplies. System fuel and electric power demands, and operation when not connected to main utilities or when not receiving supply

supporting the extended periods that are consistent with support for strategic analysis products, will be included.

- Reliability KSA. Reliability is measured by evaluating Mission Reliability (MR) and Logistics Reliability (LR). Mission Reliability is a measure of the ability of an item to perform its required function for the duration of a specified mission. Logistics Reliability is a measure of the ability of an item to operate without placing a demand on the logistics support infrastructure for repair or adjustment. Both of these metrics are design metrics that are considered to have the most impact on a program's operational availability and ownership costs.
- Ownership Cost (OC) KSA. This KSA addresses the balance of 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.
- Maintainability (MX) KSA. This KSA looks at the corrective maintenance and maintenance burden. Corrective maintenance looks at all of the actions that are performed as a result of any failure, to restore a system, subsystem, or component to a required condition. Maintenance burden is an evaluation of a systems maintainability related to the demand for maintenance manpower.
- 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.[5]

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

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

	Am	Ao	EP	MR	OR	OC	MX	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		

Table 1 - CBM+ Objectives and Metrics

Continual improvements resulting in increased readiness, technology enhancements, or new processes must be acquired or developed. These improvements often result in the use of resources that are always limited. Even with a policy that requires its implementation, CBM+ must "buy its way" into a 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 to support other platforms and programs and joint activities.

1.2.6 Benefits of CBM+

This Guidebook brings together many different ingredients required for a successful CBM+ strategy. CBM+ offers a multitude of benefits that enhance maintenance practices and system performance. These include:

- Greater Productivity: CBM+ optimizes maintenance processes, reducing unnecessary downtime. Maintenance personnel focus on critical tasks improving overall productivity.
- Shorter Maintenance Cycles: Predictive maintenance minimizes lead time for repair. CBM+ ensures timely interventions and reduces system outages.
- Lower Costs: Evidence-based maintenance avoids unnecessary actions.
- Increased Quality: CBM+ integrates data-driven decision-making. Maintenance actions are aligned with actual requirements.
- Better Availability: CBM+ maximizes system uptime. Components receive attention only when needed.
- Enhanced Reliability of Materiel Resources: CBM+ ensures that systems remain reliable by performing interventions on a proactive approach that helps prevent unexpected failures.

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):[6]

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

- At the tactical level, CBM+ may mean new tools, test equipment, and embedded on-board 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 describes 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.
- 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, equipment, and maintenance documentation. Data collected be it from embedded sensors, such as health and usage monitoring systems, or maintainer documentation 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.

1.2.7 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 in deployed environments. 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 Product Support Strategy. In concert with the other PS 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, OA, EP, MR, LR, OC, MX, and MDT. 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 using CBM+ processes and technologies. Fully implemented, CBM+ improves maintenance decisions and helps integrate all functional aspects of life-cycle management processes (such as funding, acquisition, distribution, supply chain management, and system engineering).

1.2.8 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 discusses CBM+ Implementation Prerequisites ("DoD Maintenance Programs" and "Examples of Component 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.

- 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 forms a "game plan" to assist the readers in formulating their own CBM+ implementation strategies tailored to their 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:

- The DoD Senior-level Sustainment Leaders, through a supporting Working Group (WG), monitors and coordinates the CBM+ strategy through research and projects. The CBM+ WG 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.[7] To view the above report and to obtain the most current information on the DoD's CBM+ initiative and the CBM+ WG, see https://www.acq.osd.mil/log/MR/cbm+.html

This Guidebook is an evolving document as more individuals and organizations focus on improving their maintenance processes through new technologies, practices, and processes.

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

Comments and suggestions to improve this Guidebook are welcome by emailing us at: OSDAS-COP4ST@groups.mail.mil.

2 CBM+ Implementation Prerequisites

When you begin to think about implementing CBM+, you need to ensure that you've prepared yourself and your workforce for the change. It is also important to ensure that you've evaluated the existing maintenance program and the processes that are currently in use. Doing this initial prerequisite work will help inform the decisions you make later as you implement CBM+ principles into your program. Table 2 summarizes the essential information and provides some key questions you should answer.

1. Have I thoroughly reviewed the CBM+ introductory materials in Section 1 and the addition references in Addendum F 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 a CBM+ environment?
4. Is additional research and training needed to familiarize myself and team members with CBM+ background, policies, technologies, or other relevant information?
5. Do I have adequate training for myself and the team and has it been accomplished?
6. Have I reviewed ongoing DoD and Service CBM+ programs to understand the status, characteristics, and issues associated with these efforts?

Table 2 - CBM+ Strategy Checklist

2.1 DoD Maintenance Programs

Maintenance programs for DoD materiel shall be structured and managed to achieve inherent performance, safety, and reliability levels of the materiel. Maintenance tasks restore safety and reliability to their inherent levels when deterioration has occurred. Maintenance programs are structured for meeting readiness and sustainability objectives (including mobilization and surge capabilities) of national defense strategic and contingency requirements. In addition, maintenance programs shall employ maintenance concepts that optimize process technologies, organizational structures, and operating concepts to deliver efficient and effective performance to the operating forces.[8]

2.1.1 The Advantages of Proactive Maintenance

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[8] DoD Directive 4151.18, *Maintenance of Military Materiel,* August 31, 2018.

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 tun 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 unscheduled in the sense the failure occurred unpredictably. Reactive maintenance restores an item to a serviceable condition after the failure has occurred.

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

    - Preventive or scheduled maintenance can be accomplished using an interval-based schedule. This interval could be a set number of calendar periods, 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, alternatively, triggered after detection of a condition that may lead to failure or degradation of functionality of the weapon system, equipment, or component.

    - Predictive maintenance can be categorized as either diagnostic or prognostic. Diagnostics identify an impending failure, while prognostics add the capability to create a reliable forecast of the remaining useful life. A reliable forecast of the remaining useful life is an obvious benefit to enable optimum mission readiness and maintenance planning.

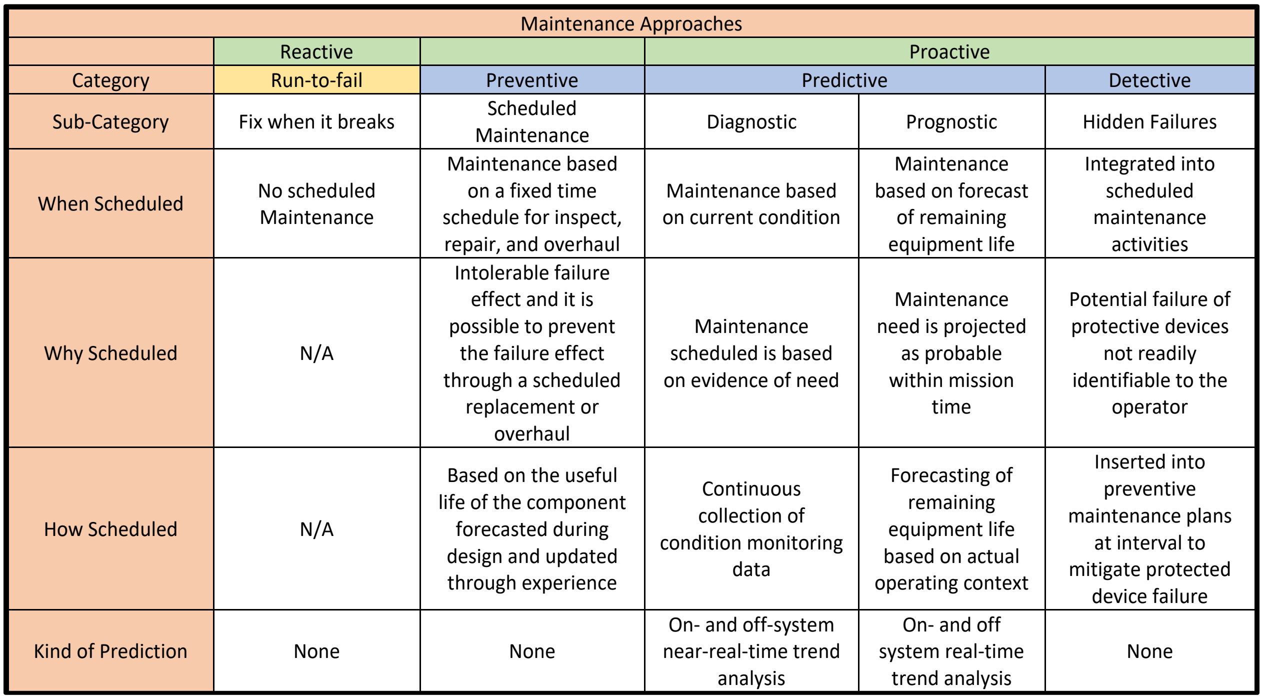
    - Detective maintenance (also known as failure finding) determines if a protective device is still working and thus, will be capable of providing protection in the event that the protected function fails. These are categorized separately in that that a failure would not otherwise be evident to the operator. They are commonly referred to as “hidden failures.”

More information on the development of maintenance programs and requirements can be found in DoD Directive 4151.18, “Maintenance of Military Materiel,” DoD Instruction 4151.22, “Condition-Based Maintenance Plus for Materiel Maintenance,” and DoD Manual 4151.25, “Reliability-Centered Maintenance.”

Proactive maintenance can help ensure that the equipment will perform as designed. Proactive maintenance actions, like lubrication and filter changes, or even more extensive replacement of failure causing parts, will generally allow the equipment to run more efficiently and meet designed service lives, resulting in greater readiness and potential cost savings. While it will not prevent all potential end item failures, proactive maintenance can decrease the number of failures and overall equipment downtime. Minimizing these failures translates into savings both in maintenance and future capital equipment replacement costs. When failure does occur or is imminent, corrective maintenance will be required.

2.1.2 Reactive and Proactive Maintenance Approaches

There are a wide range of maintenance approaches that can be used to structure a maintenance program, including the use of CBM as part of a predictive maintenance process. Figure 6 illustrates this range.



Maintenance Approaches					
	Reactive		Proactive		
Category	Run-to-fail	Preventive	Predictive		Detective
Sub-Category	Fix when it breaks	Scheduled Maintenance	Diagnostic	Prognostic	Hidden Failures
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	Integrated into scheduled maintenance activities
Why Scheduled	N/A	Intolerable failure effect and it is possible to prevent the failure effect through a scheduled replacement or overhaul	Maintenance scheduled is based on evidence of need	Maintenance need is projected as probable within mission time	Potential failure of protective devices not readily identifiable to the operator
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 operating context	Inserted into preventive maintenance plans at interval to mitigate protected device failure
Kind of Prediction	None	None	On- and off-system near-real-time trend analysis	On- and off system real-time trend analysis	None

Figure 6 - Maintenance Approaches

In the past, the alternative to reactive maintenance has most often been time-based or scheduled preventive maintenance. Under this approach, major maintenance often 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 attempts to attain a predictive approach, if falls short of a true predictive strategy triggered by the assessment of actual equipment condition.

Although there are multiple approaches to accomplishing maintenance of weapon systems 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. Each approach to maintenance has positive and negative aspects. For example, preventive maintenance or timed component change outs may reduce failures, but they could also increase maintenance downtime and consequently decrease operational availability.

Based on equipment characteristics, operating context, 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 equipment failures and corresponding increases in overall equipment life and reduced total life-cycle costs. Figure 7 demonstrates this objective.

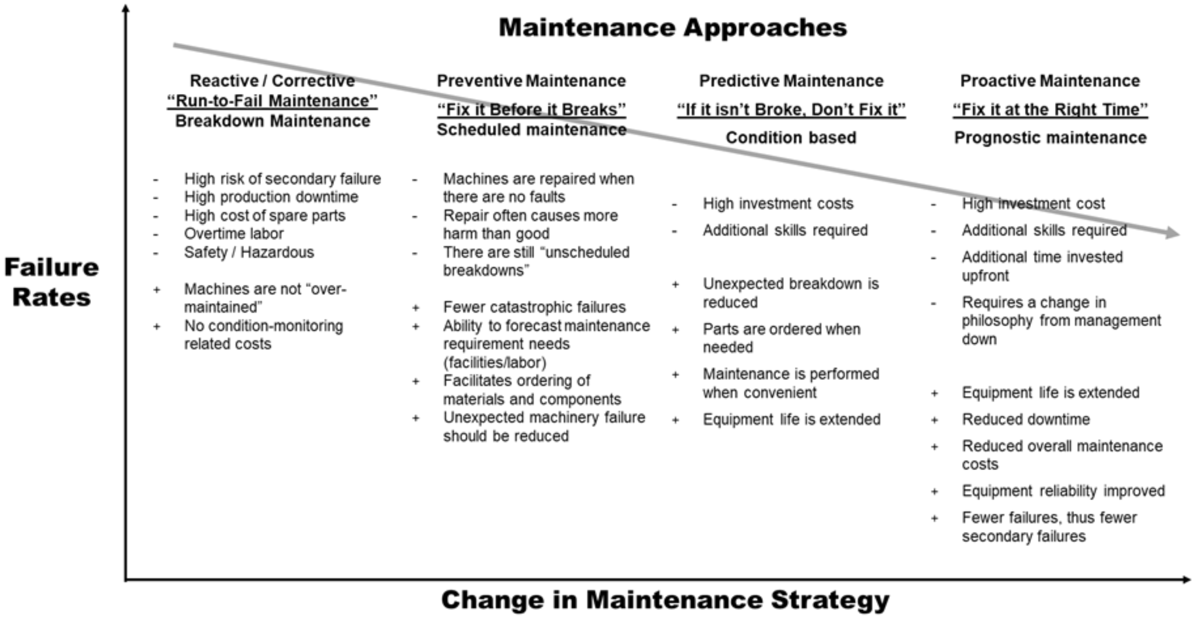


Figure 7 - Evolution of Maintenance Strategy

Using the family of capabilities under CBM+ will improve the detection, prediction, and pred-failure reaction to potential failure causing conditions. Therefore, CBM+ is a valuable tool in improving greater use and increased effectiveness of a maintenance program. The basic intent of this guidebook is to facilitate DoD's evolution toward greater application of the predictive and proactive approaches to maintenance using the capabilities inherent in the CBM+ strategy. Figure 8 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 proactive actions while lessening traditional scheduled preventive actions.

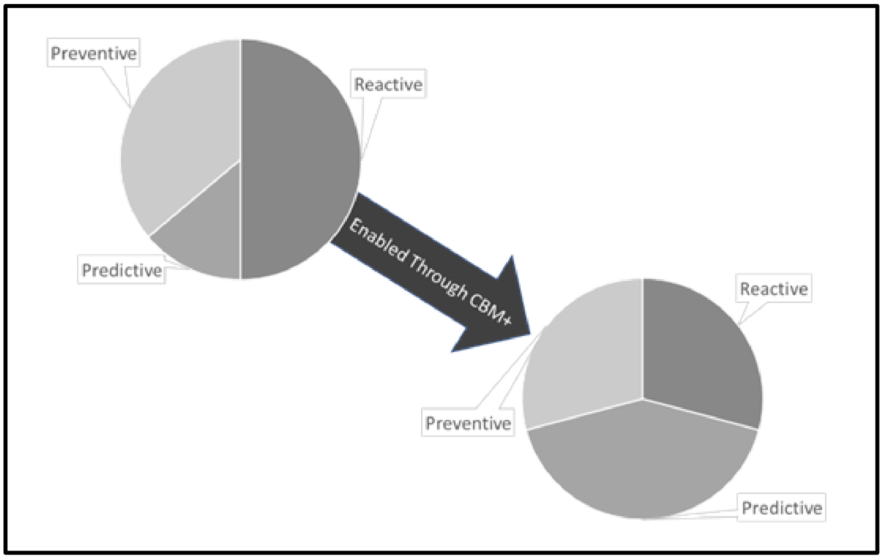


Figure 8 - Maintenance Strategy Transition

2.2 Examples of Component CBM+ Initiatives

In 2005, a survey was conducted to capture planned and on-going CBM+ initiatives. An additional survey to determine maturity of those Service-level programs was conducted in 2017. The DoD Inspector General conducted an audit in 2021 and the GAO followed with an audit in 2022. Notably, considerable progress has been made by the Military Services in various aspects of CBM+ implementation. The following is a short summary of select programs that are benefiting from the use of implementing and executing CBM+ principles.

2.2.1 Army

- Army rotary wing aircraft (namely the CH-47 Chinook, UH-60 Blackhawk, and AH-64 Apache) have been outfitted with digital source collectors to gather data on aircraft component and airframe health. The Aviation and Missile Command reviewed data associated with a series of previous transmission failures to identify and proactively replace transmissions in ten aircraft assessed to have a high probability of failure.

- Soldiers from the 2nd Armored Brigade Combat Team, 3rd Infantry Division at Ft. Stewart, GA implemented digitized maintenance processes to conduct maintenance tasks and fault verification across several of their ground platforms.

- The Army's Artificial Intelligence Integration Center developed a tool to improve analytics for Army Aviation units. A fault and failure forecasting model uses historic records on part replacements to predict the probability of serialized component replacements on aircraft. Beyond predicting part failure, the tool also aids unit leaders with prioritizing aircraft daily maintenance actions, tracks parts on order, and projects anticipated aircraft usage based on flight records.

2.2.2 Navy

- The ***Fleet Maintenance Effective Review (FLEETMER)*** and ***Classic RCM Workshops*** incorporate a Naval Sea System Command continuous improvement process that applies reliability-centered maintenance to current maintenance practices and validates ship maintenance requirements.

- The ***Enterprise Resource Monitoring (eRM)*** is an online automated machinery condition monitoring and assessment program consisting of shipboard and integrated shore-based systems currently installed on multiple ship classes.

- The ***Integrated Logistics Assessment (ILA)*** process at NAVSEA is used to audit acquisition programs Maintenance Planning & Management processes. The ILAs ensure that CBM+ and RCM are integrated into the maintenance planning process for all weapon systems under development.

2.2.3 Air Force

- The USAF developed and designated Predictive Analytics and Decision Assistant (PANDA) to be the enterprise system of record for predictive maintenance. This tool integrates proven data aggregation, data analytics, long range supply forecasting, predictive failures (eRCM), degradation detection (Sensor Based Algorithms), notifying and actioning maintenance and predictive fleet health all in one concise software solution.

- Sensor Based Algorithms (SBAs) are currently deployed across three MDS's with an additional five MDSs planned in FY25. Currently, SBAs monitor 5,800+ LRUs for degradation across 475+ aircraft and are responsible mitigating ~150 unscheduled maintenance events over the last six months.

- The USAF is collaborating with USSOCOM and AFSOC to augment and enhance data capture capabilities, developing and delivering Advanced Maintenance and Troubleshooting System (AMATS) for numerous aircraft variants across the enterprise.

2.2.4 Marine Corps

- The USMC has implemented data logging technology into nearly 900 vehicles withing the JLTV, MTVR, and LVSR families. In FY25, the Corps plans to further expand this capability adding the loggers to the TRAM, MCT, and HYEX families of vehicles.

- Data from 16 units spanning 3 MEFs is collected into management information systems. This data is then aggregated and used to construct Enterprise Level Dashboards to track fleet health and performance.

2.2.5 Program Updates

The occasion and feasibility to apply or insert CBM+ technologies and processes varies with the maturity and complexity of the weapon system and equipment, the resources available to accomplish individual initiatives, and the operational performance experienced in the field. Service CBM+ projects are continually being revised and updated. New pilots are continuously initiated to evaluate new technologies and capabilities.

1.1.1. Our office works to ensure that information on CBM+ programs, pilots, lessons learned, and best practices are shared across the Department. Updated information can often be found on the individual Service websites, the Office of the Secretary of Defense CBM+ website, or within the Community of Practice for Sustainment (COP4ST) suite all of which are included in the reference section of this document.

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3. Essential Elements of CBM+

Implementation and execution of CBM+ in DoD activities requires a comprehensive understanding of the numerous elements and a realization that successful execution 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 Life Cycle Sustainment Plan of the weapon system or equipment. The six subgroups are shown in Figure 9.

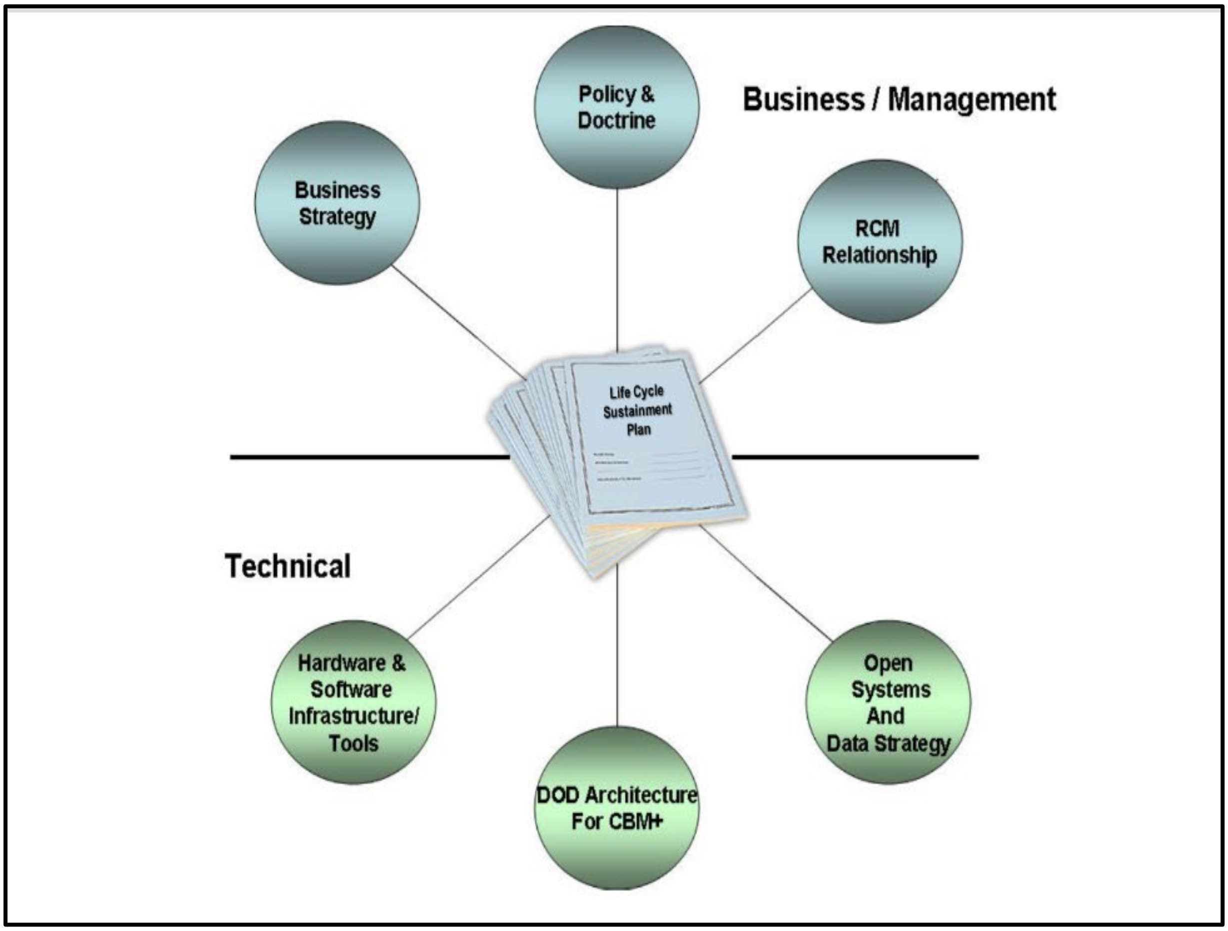


Figure 9 - CBM+ Primary Categories and Sub-Groups

Table 3 further summarizes the basic requirements of a comprehensive CBM+ strategy.

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:

Business Management	**Technical**
Policy and doctrine	Hardware & Software Infrastructure / Tools
Business strategy	DoD architectural framework for CBM+
RCM Relationship	Open systems and data strategy

3. Policy and doctrine: Recognize the guidance from senior DoD and Service leadership covering the requirement to implement and execute CBM+ strategy, the objectives, and benefits of the effort, who is responsible, and the target end state.
4. Business strategy: Identify the business needs and processes needed to implement CBM+ objective of improving maintenance effectiveness, and the approach to accomplishing the CBM+ business case.
5. RCM Relationship: Implement and execute 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. Hardware & Software Infrastructure / Tools: 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+ practitioners to implement and execute CBM+.
7. DoD Architectural Framework 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+ ecosystem.
8. Open systems and data strategy: Acquire technical capabilities and procedures available to CBM+ practitioners to accomplish the most effective integration of hardware, software, and data management components. 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.

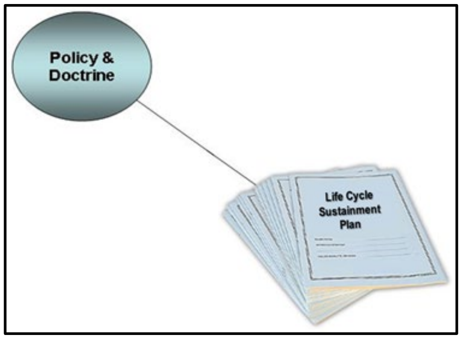
Table 3 - CBM+ Basic Requirements

3.1. Business/Management Elements

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 policy and doctrine, business strategy, and the RCM relationship.

3.1.1. Policy and Doctrine

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



3.1.1.1. 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 directed that CBM+ be “implemented to improve maintenance agility and responsiveness, increase operational availability, and reduce life cycle total ownership costs.” The policy required the Services and 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 is in commercially supported systems/programs.”[9]

3.1.1.2. 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. This requires the PMs to take a responsibility for CBM+ implementation and translate activities into specific requirements that should be included in key performance parameters (KPPs) that document the implementation throughout a system’s life cycle.

The PM is responsible for approving life-cycle trades throughout the acquisition process. Reliability-Centered Maintenance (RCM) and Condition-Based Maintenance Plus (CBM+), see DoD Manual 4151.25 and DoD Instruction 4151.22, are important initiatives to enable the performance of maintenance based on evidence of need as provided by RCM analysis and

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

other enabling processes and technologies. Additional guidance for PMs for the full range of acquisition life-cycle activities, including development of CBM+ capabilities, is contained in the Acquisition Guidebooks and References. These focused guidebooks can be located at https://aaf.dau.edu/guidebooks/.

The Joint Capabilities Integration and Development System (JCIDS) Manual provides information on Key Performance Parameters (KPPs), Key System Attributes (KSAs), and their development. The JCIDS Manual can be downloaded (CAC required) at: https://jitc.fhu.disa.mil/isg/downloads/Manual-JCIDS_30Oct2021.pdf

3.1.1.3. DoD Maintenance Policy Directive

DoD maintenance policy (DoD Directive 4151.18, “Maintenance of Military Materiel”) requires minimizing maintenance 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.

3.1.1.4. DoD Policy Instruction

The DoD published the first instruction for CBM+ in December of 2007. The initial policy remained in place until it was revised in October of 2012. The publication is on its second revision and was updated in August of 2020. 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 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 operation 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.

- RCM analysis to determine maintenance requirements which drive CBM+.
- Reliability Analysis and 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.

3.1.1.5. Military Service Policies

To find current policy, please refer to the individual Service website, the DoD Publications Portal, the JCS Library, the OSD CBM+ website, or the COP4ST application suite.

DoD

DoD Instruction 4151.19, “Serialized Item Management for Life-Cycle Management of Materiel,” August 31, 2018

DoD Instruction 4151.22, “Condition-Based Plus Maintenance for Materiel Maintenance,” August 14, 2020

DoD Manual 4151.25, “Reliability-Centered Maintenance (RCM),” February 16, 2024

Army

Army Regulation 750-1, “Army Materiel Maintenance Policy,” 2 March 2023

Navy

Operations (OPNAV) Instruction 4790.16B “Condition-Based Maintenance and Condition-Based Maintenance Plus Policy,” 1 October 2015

Air Force

AFMC Instruction 21-103, “Reliability-Centered Maintenance (RCM) Programs,” 29 July 2021

DAF Instruction 63-101/20-101, “Integrated Life Cycle Management,” 16 February 2024

DAF Instruction 21-101, “Aircraft and Equipment Maintenance Management,” 8 November 2022

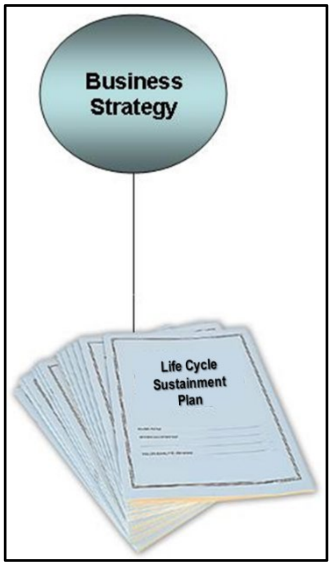
CBM+ Strategic Implementation Plan (CBM+ SIP), May 2023

2030 USAF CBM+ Vision

Marine Corps

Marine Corps Order 4151.22, “Condition-Based Maintenance Plus,” 17 January 2020

3.1.2. 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 through increased maintenance effectiveness in terms of greater productivity, shorter maintenance cycles, increased quality of the process, and better utilization of resources. In support of this requirement, the Product Support Strategy (PSS) concept should be used as a vehicle for ensuing the elements of CBM+ are fully considered as early as possible in the acquisition life cycle of a weapon system or equipment. CBM+ should be viewed as an element of the PSS, emphasizing an early focus on sustainment with 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.

3.1.2.1. CBM+ as part of the PSS Concept

Life -cycle logistics managers should incorporate the elements of CBM+ in the planning efforts, beginning as early as possible in the acquisition process. The following are examples of insertion of CBM+ considerations under PSS 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 productions 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.

PSS is discussed further in Sections 5 and 6.

3.1.2.2. 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 reactive or even a time-based maintenance, preventive, 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 resources through each Service's Planning, Programming, and Budget Execution (PPBE). 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 implementation and execution of 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 address 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.

3.1.2.2.1. 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. Ultimately, this 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.

3.1.2.2.2. 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 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. Overall cost of maintenance should be considered, including availability and cost of replacement parts, downtime, and labor costs to inspect and refurbish internal components, and post-repair testing.

A holistic view of equipment condition monitoring requires the integration of:

- Automated condition monitoring inspection results (coverall all condition monitoring techniques used, such as vibration analysis, oil analysis, and thermography).
- visual inspection results.
- fixed interval "preventive".
- opportunistic maintenance.

- equipment performance monitoring; and
- data analytics enhanced with artificial intelligence and machine learning.

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 52) may help alleviate this issue. Business rules should require the full range of monitoring capabilities to ensure full accuracy and timeliness of condition monitoring results.

3.1.2.2.3. 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 operation 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 that 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 considered, 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 those 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[10] 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 equipment. Business rules should require prudent investment in sensor, data collection, and analytic capabilities to minimize condition monitoring and failure analysis errors.

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

3.1.2.2.4. 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 rule 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 develop 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 a rudimentary "first-pass" vibration or oil analyses that are conducted by equipment operators to determine whether a particular item of 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 communication 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.

3.1.2.2.5. Business Need 5 – Need 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 increased intervals between repetitive inspection type maintenance tasks.

- 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 modifications 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 several ways, including designing in sensor capabilities, built-in-tests, 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 (often 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-offs 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.

3.1.2.2.6. Business Need 6 – Need to Reduce System Mean Down Time (Logistics Responsiveness)

The increased efficiency of the maintenance process attainable through implementation and execution of CBM+ should be evidenced by significant reduction in overall mean down times for those systems and component where CBM+ capabilities are instantiated. 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.” 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, 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.

3.1.2.2.7. Business Need 7 – Need to Optimize Equipment 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 such as the use of digital twins and modeling and simulation tools may also impact equipment design by reducing the need for some component redundancies and improving maintenance strategies and approaches.

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 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.

3.1.2.3. 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 that 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 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 10.

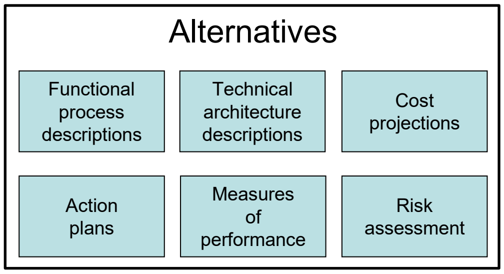


Figure 10 - Alternatives within a Business Case Analysis

It is important to realize that the 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 organizations’ 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 cost of implementation, but expresses return or benefits in both tangible (dollars, personnel, and facilities) and intangible (improved performance, safety or time saved) terms. The BCA 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, whichever is less. The decisions to include or exclude a CBM+ technology should be based on a BCA. 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.

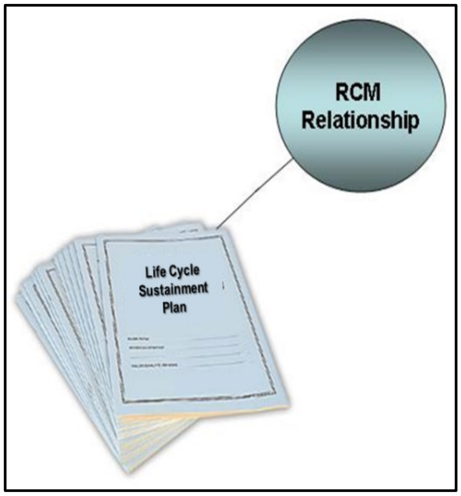
Regardless of where an organization is in its efforts to implement CBM+, early in the acquisition of a new weapon system or well into the sustainment phase of a weapon system or equipment, the BCA is a valuable management tool. A well-constructed business case presents management with decision-making 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://www.dau.edu/tools/product-support-business-case-analysis-bca-guidebook.

DAU also offers learning opportunities through their catalog located at https://www.dau.edu/search?search=BCA&f%5B0%5D=content_type%3Acourses.

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 BCA should be incorporated into applicable requirements, programming, and budgeting justification documents.

3.1.3. RCM Relationship



There is a close relationship between CBM+ and RCM. The RCM process provides the basis for determining initial maintenance requirements based on the analysis of equipment failures relative to the likelihood and severity of expected equipment failures. RCM analyzes possible impacts on personnel and regulatory requirements, ability of the organization to accomplish assigned mission, and cost impacts of failure mitigation versus planned reaction against the likelihood and severity of the definable failure mechanism apparent in the current implementation of the design. Therefore, RCM provides the minimum rules for determining evidence of need for a CBM program and the starting point for escalation to a program that further incorporates the expectations for CBM+. With advances in technology, such as sensor hardware, modeling and simulation, and ability to transmit data using equipment health monitoring systems, machine-to-machine communications, and internet of things (IOT), the RCM process can be used to develop an expanded system to take advantage of the achieved efficiencies in the maintenance process. When implemented effectively in an integrated fashion, 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 best cost. Specifically, RCM identifies the concepts and methods needed to select technically appropriate maintenance actions. Appropriate may include predictive and preventive tasks that will prevent or identify failures (failure-finding tasks), proactive management of run-to-failure components, identification of 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."[11] 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

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

readiness."[12] RCM analysis considers the failure process and related reliabilities of equipment, the severity of the related consequences of the 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 reactive. 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. Reactive 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.

The current approaches for maintenance on DoD equipment, using reactive and time-driven (preventive) strategies, 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 condition-based maintenance (CBM) actions; actions based on evidence of need. Once a possibility of failure is identified, it can be analyzed to determine if a CBM approach is technically appropriate and effective. Figure 11 depicts what is called a classic "P-to-F" curve.

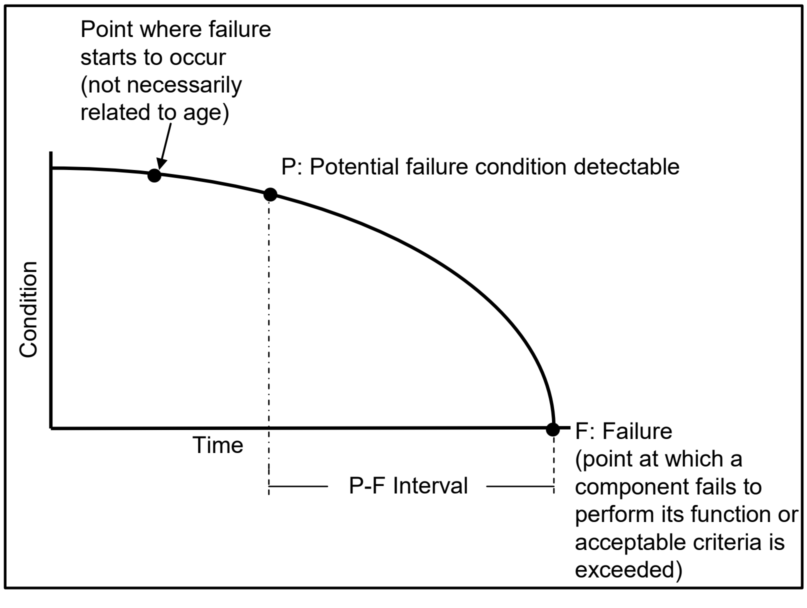

Figure 11 - Classic P-to-F Curve

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[12] NAVAIR Manual 00-25-403, "Naval Aviation Reliability-Centered Maintenance Process," September 01, 2023.

The P-F curve illustrates that many types of equipment will show detectable signs of impending failure before the equipment 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.

Incorporating CBM+ technologies to a condition-based approach will better enable system operators and their maintenance support teams to be made aware of pending failures in advance. This will provide the opportunity to accomplish appropriate actions, at the best opportunity, to prevent the loss of use and cost related to experiencing the actual equipment failure.

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 in 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 around 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 five 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 analysis provides the maintenance requirement baseline necessary to construct a business case for implementation of CBM+ technologies. 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 on the maintenance analysis process. Table 4 relates the RCM process steps with representative capabilities of CBM+.

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. When the system falls below the desired performance standards.	Provides diagnostic tools to assess degree of system component degradation. Track 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. Identifies and analyzes failure effects at the local, subsystem, and effect – platform/mission. Applies information from Interactive Electronics 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 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 failures 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.

Table 4 - CBM+ Capabilities Relative to RCM Process Steps

CBM+ is not a process; it is a comprehensive strategy to select, integrate, and focus 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 numerous capabilities and initiatives, some procedural and some technical, that can enhance the basic RCM tasks. In this way, CBM+ enables a more effective RCM program.

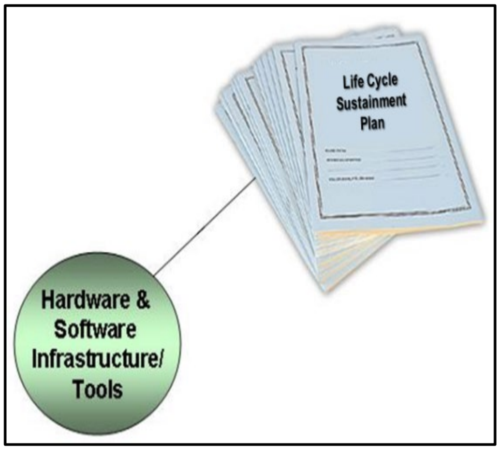
If the RCM analysis suggests revision of maintenance tasks, then the maintenance manager should accomplish an assessment of how CBM+ capabilities may be applied to support the revised maintenance task procedures. Often, the revised tasks require fundamental changes to the maintenance strategy such as 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, but 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 the RCM and CBM+ have a mutually beneficial relationship. From a weapon system or equipment perspective, health management with RCM analysis becomes technology insertion without a justified functionality. Conversely, collection of aggregated or platform-centric heal 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.

3.2 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.

3.2.1. Hardware & Software Infrastructure / 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 hardware 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 approached 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 12. 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.

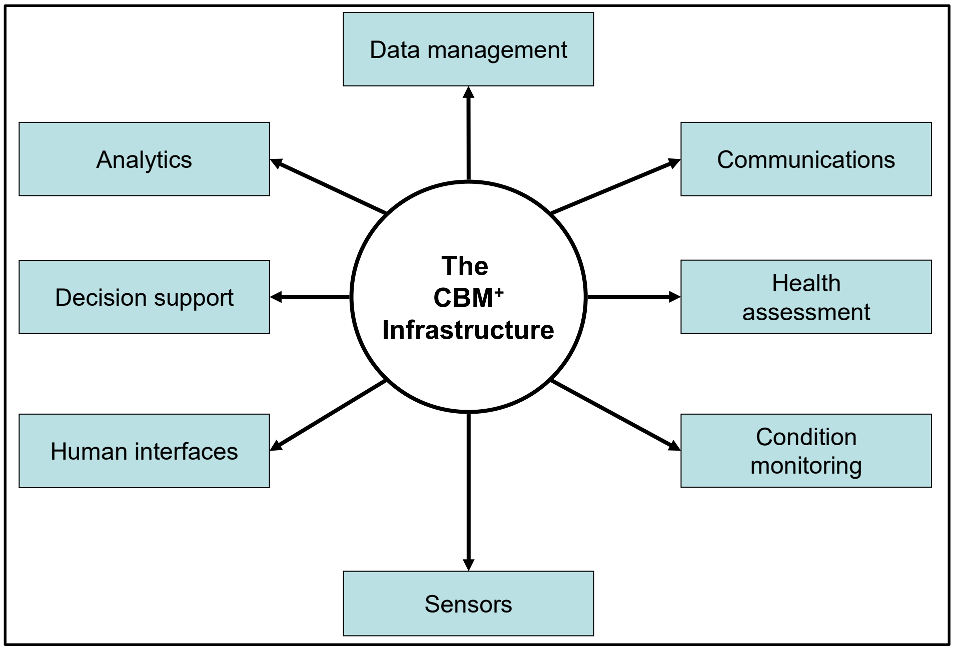


Figure 12 - CBM+ Infrastructure Areas

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.

3.2.1.1. Sensors

Sensors are physical devices that monitor, record, or transmit equipment or component operating parameters or conditions. Then 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.

3.2.1.2. Condition Monitoring

Condition monitoring is a maintenance process in which the condition of the equipment's 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 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 capability. Condition monitoring includes technologies such as

- vibration measurement and analysis,
- infrared thermography,
- oil analysis and tribology (friction/wear analysis)
- ultrasonics, and
- motor current analysis.

3.2.1.3. 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 operation 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 of 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 health 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 using embedded processors. The second aspect of health assessment is the off-system processing of collected sensor data from storage and data 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.

3.2.1.4. 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 collected 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 communication 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, the CBM+ website and the COP4ST application suite.

3.2.1.5. Data Management

Data management is central to implementation of CBM+. Data management consists of acquiring data (e.g., through sensors or acquisition techniques), manipulating data into meaningful for (e.g., converting analog to digital), storing data (electronically in digital form), transmitting data (through electronic means), access 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 the collects, integrates, and stores an organizations' 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 organizations and locations. One issue relating to the CBM+ database concerns data access and sharing. For example, if the CBM+ database comprises the single repository for condition, performance, trending history, and other data categories, then each database user including government and contract activities will require access to the pertinent portions of the database. Any effective CBM+ database should have will-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 13 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 organization or process requirements and the availability of an effective communications capability.

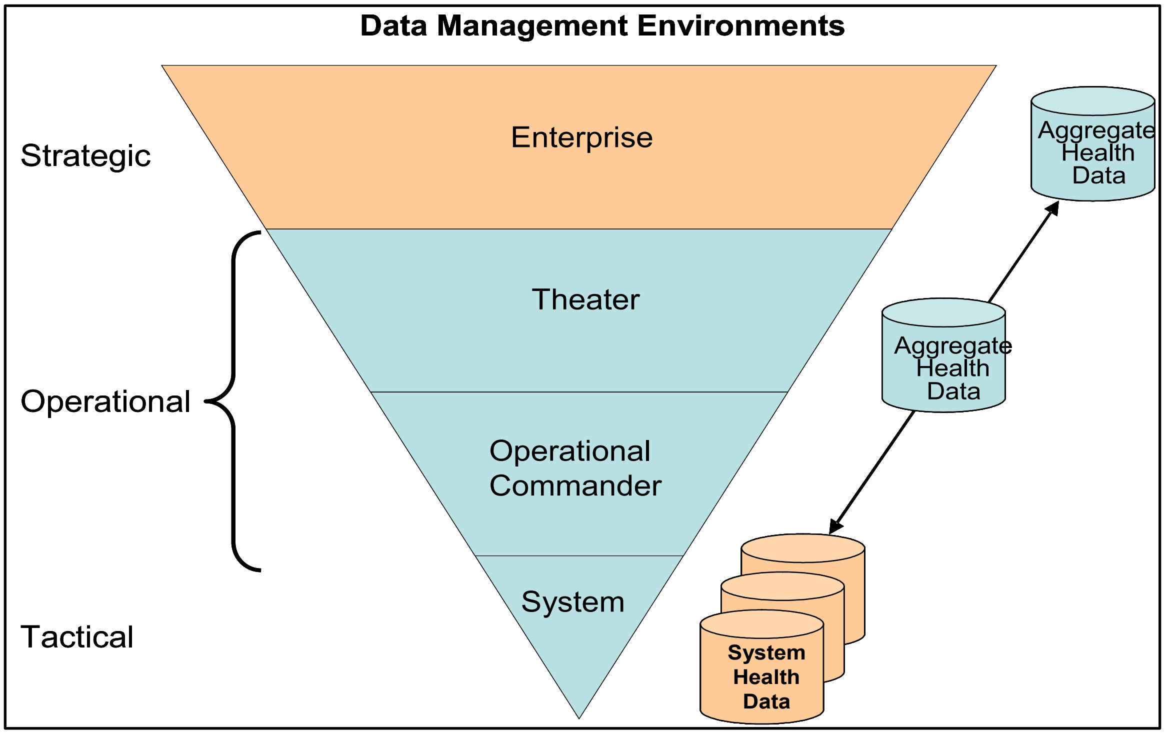


Figure 13 - CBM+ Notional Data Environment

3.2.1.6. Analytics

Analytic 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, considering estimates of future usage profiles. Root-cause analysis and tailored analytic algorithms 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 operation 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.
- Prognostics assessment is the capability to perform a reliable in sufficiently accurate prediction of the remaining useful life of equipment. This allows the condition monitoring system to do more than just react to threshold crossings and diagnostic alerts.

Depending on the organization’s requirements for CBM+ capabilities, data collection and health management analysis may be used for a range of purposes, from a single condition assessment for a single component to a full condition assessment with projections of useful life expectancies across a fleet of equipment. Figure 14 shows generic possible inputs and output results from a reasonably comprehensive prognostic software model.

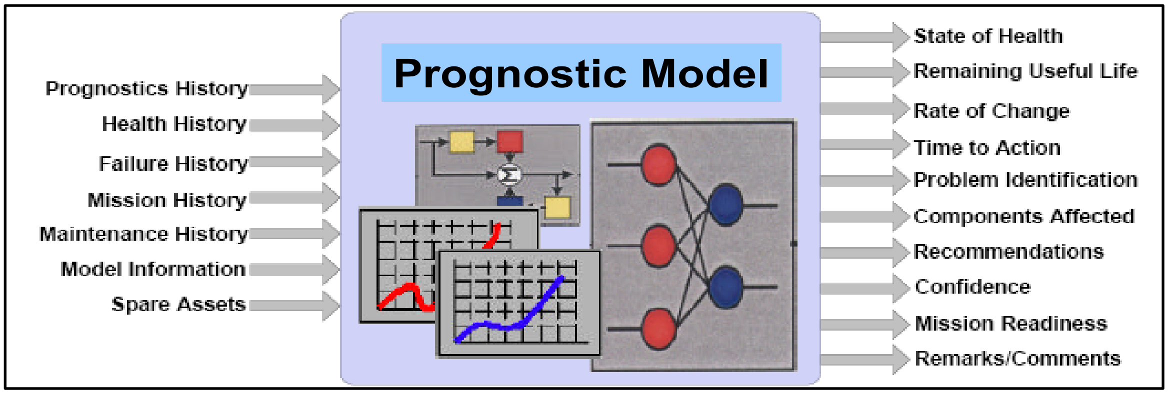


Figure 14 - Generalized Inputs and Outputs from a Prognostic Model

A prognostic model must be flexible enough to accept many difference sources of information to predict the remaining useful life adequately and accurately. By predicting the remaining useful life, the prognostic capability assists the operators and managers in actively managing their maintenance resources and determining maintenance actions. Effective use of prognostic assessment or “prognostics” is the goal of predictive maintenance.

3.2.1.7. Decision Support

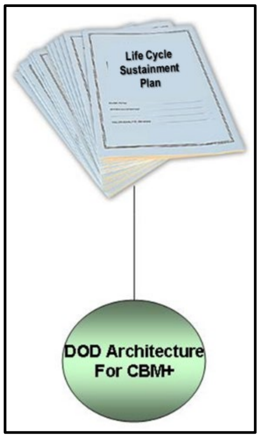
Regardless of its sophistication, a complete CBM+ capability includes the ability to make maintenance and related support decisions based upon the available condition data. This involves using decision-support software to assess equipment operating reliability and availability, identify needed changes 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 is cush 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 analytical elements. The primary function of the decision support is to recommend maintenance or engineering actions and alternatives and to understand the implications of each recommended action. Recommendations includes 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 consider such factors as operation 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.

3.2.1.8 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 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 from 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.

3.2.2. DoD Architectural Framework 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 organization and functional boundaries, including Joint and multinational boundaries.

A full discussion of the DoD AF is available at: https://dodcio.defense.gov/Library/DoD-Architecture-Framework/

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 bases for information exchange and health assessment capabilities.
- Identifying the 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 interfaces 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 systems life cycle as part of the Joint Capabilities Integration and Development System (JCIDS) requirements generation; the DoD Planning, Programming, Budgeting, and Execution (PPBE) process; and the Defense Acquisition System process.

DoDAF organizes the DoDAF-described Models into the following viewpoints:

- The All Viewpoint describes the overarching aspects of architecture context that relate to all viewpoints.
- The Capability Viewpoint articulates the capability requirements, the delivery timing, and the deployed capability.
- The Data and Information Viewpoint articulates the data relationships and alignment structures in the architecture content for the capability and operational requirements, system engineering processes, and systems and services.
- The Operational Viewpoint includes the operational scenarios, activities, and requirements that support capabilities.
- The Project Viewpoint describes the relationships between operational and capability requirements and the various projects being implemented. The Project Viewpoint also details dependencies among capability and operational requirements, system engineering processes, systems design, and services design within the Defense Acquisition System process.
- The Services Viewpoint is the design for solutions articulating the Performers, Activities, Services, and their Exchanges, providing for or supporting operational and capability functions.
- The Standards Viewpoint articulates the applicable operational, business, technical, and industry policies, standards, guidance, constraints, and forecasts that apply to capability and operational requirements, system engineering processes, and systems and services.
- The Systems Viewpoint, for Legacy support, is the design for solutions articulating the systems, their composition, interconnectivity, and context providing for or supporting operational and capability functions.

A presentation of these viewpoints is portrayed in graphic format (Figure 15):

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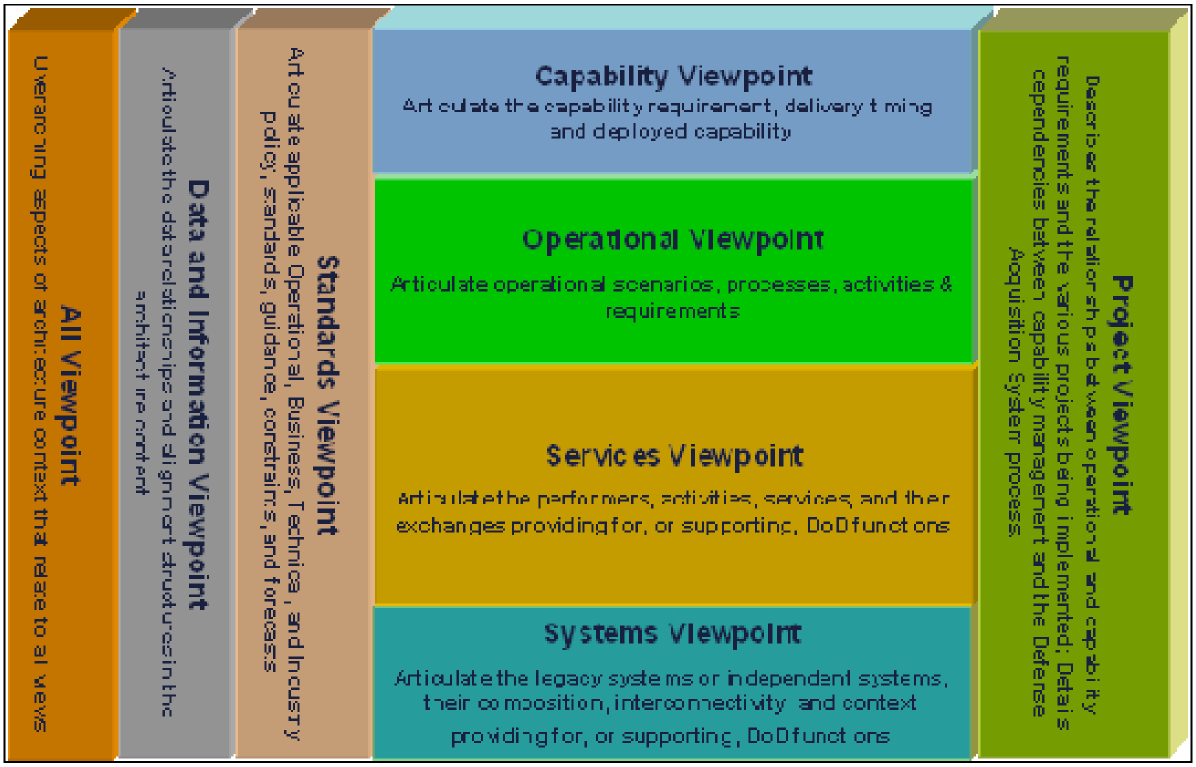


Figure 15 - DoDAF Architecture Product Relationships

By developing these architectural products early in CBM+ implementation, maintenance managers will have a significantly greater understanding 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 16 is an example of one approach to a CBM+ Operational Concept Graphic.

Architectural development often 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 for both 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.

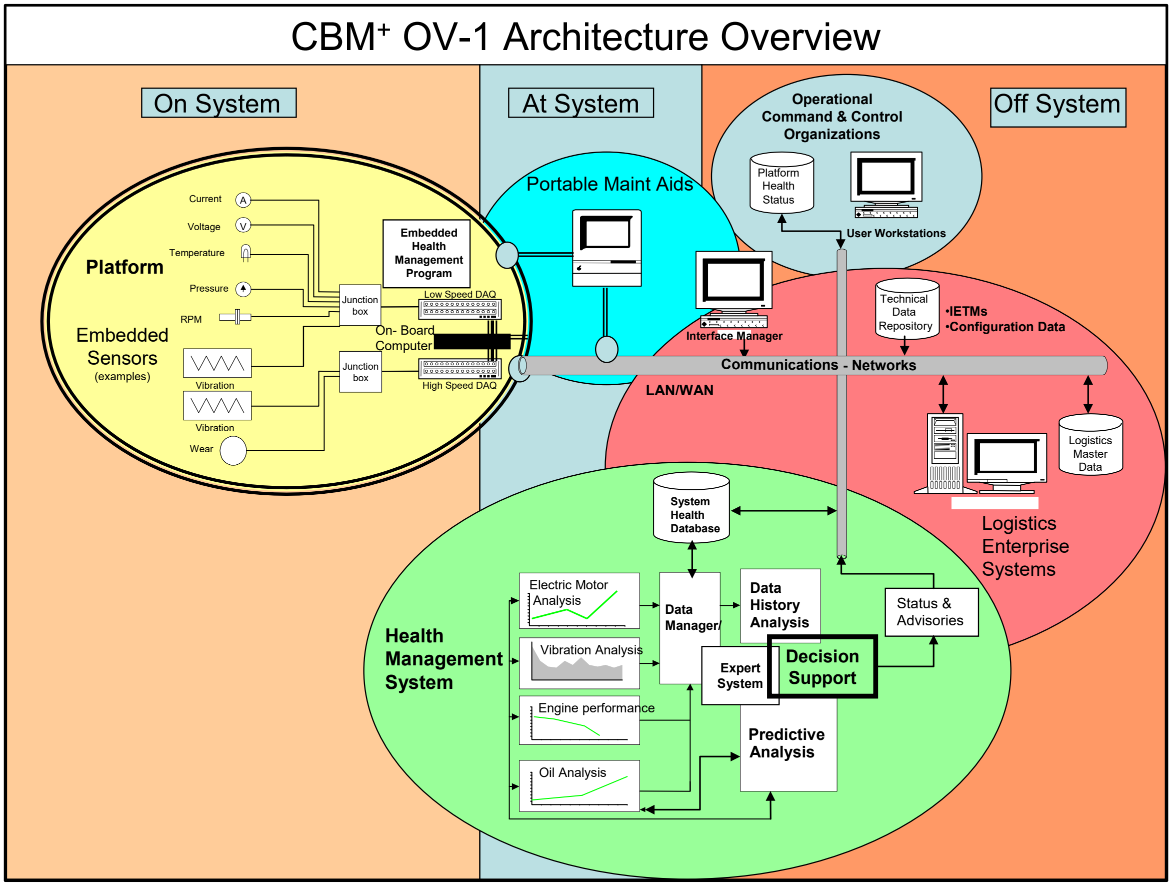


Figure 16 - CBM+ Generic Architecture Overview

- OV-5a and OV-5b, the Operation Activity Decomposition Treen and the Operational Activity Model, describe 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 Resource Flow Description purpose is to define capability requirements within an operational context. The OV-2 may also be used to express a capability boundary. The OV-2 can be used to show flows of funding, personnel, and materiel in addition to information. A specific application of the OV-2 is to describe a logical pattern of resource (information, funding, personnel, or materiel) flows.

- OV-3, the Operational Resource Flow Matrix, provides further detail of the interoperability requirements associated with the operational capability of interest. The focus is on Resource Flows that cross the capability boundary.

- SvcV-3a and SvcV-3b, the Systems-Services Matrix and the Services-System Matrix describes relationships among or between systems and services in a given Architectural Description. It can be designed to show relationships of interest, (e.g., service-type interfaces, planned vs. existing interfaces).

- StdV-1 and StdV-2, the Standards Profile and the Standards Forecast, lists all the standards that apply to solution elements. The StdV-2 can also provide descriptions of emerging standards and potential impact on current solution elements, within a set of timeframes.

Descriptions and examples of these documents , including their formats, are available on the DoD Chief Information Officer website https://dodcio.defense.gov/Library/DoD-Architecture-Framework/.

The Joint Assessments and Standards Management provides developers with access to the technical standards necessary for development of system architectures and implementation of systems. Access to the Joint Assessments and Standards Management(JSAM) is available online at https://jasm.apps.mil/my.policy with a DoD Common Access Card (CAC) and registration.

The JSAM includes:

- Information for program managers with the capability to build system viewpoints; 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 the DoD.

JSAM standards are used with the 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). JSAM also provides the ability to specify profiles of standards that programs will use to deliver net-centric capabilities.

3.2.2.1. Putting the Pieces Together – A CBM+ Architecture Approach

There are many 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 view 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.

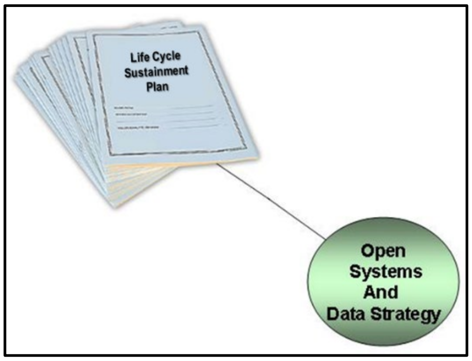
3.2.2.2. Validation and Verification

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 operation and systems views that govern the manual processes and automated systems that accomplish data collections, 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 modes 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 facilitates 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.

3.2.3. 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 know and authorized unanticipated uses can access any information and can post their contributions for enterprise-wide access."[13] 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.

3.2.3.1. Open Systems

The open-systems approach in 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 forma 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 systems 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, must apply open standards for all critical interfaces

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

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 his disparate set of components, commercial standards relating to CBM+ information flows and related process elements have been established by the International Organization for Standardization (ISO) and other standards management organizations, such as the Institute of Electronics and Electrical Engineers (IEEE) and the Society of Automotive Engineers (SAE).

The Machinery Information Management Open Systems Alliance (MIMOSA)[14] 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. Form a data management viewpoint, it is highly desirable that CBM+ data exchanges and storage conform to 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 5 lists examples of standards available to CBM+ implementers.

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[14] 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.

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.	17359.0:2003	ISO
Specifies definitions of terms used in condition monitoring and diagnostics of machines	13372:2012	ISO
Establishes guidelines for software specifications related to data processing, communication, and presentation of machine condition monitoring and diagnostic information.	13374 (Volumes 1 -4)	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	13379:2012	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)	SAE
Standard for Evaluation Criteria for Reliability-Centered Maintenance (RCM) Process	JA1011	SAE
A Guide to the Reliability-Centered Maintenance Standard.	JA1012	SAE
Standard for a Smart Transducer Interface for Sensor 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 function characteristics of a serial data bus originally designed for use with military avionics	1553	Military Standard (MILSTD)
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 chucks 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 of Aerospace Industries Association

Table 5 - Examples of Standards Available to CBM+ Implementers

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 and can be downloaded on the DoD Assist Quick Search site: https://quicksearch.dla.mil/qsSearch.aspx

The Joint Assessments and Standards Management (JSAM) is an online repository of Information Technology (IT) standards. JSAM online supports the continuing evolution of the JSAM and the automation of all its processes and is the repository for information related to DOD IT and National Security Systems (NSS) standards. JSAM should be used by anyone involved in the management, development, or acquisition of new or improved systems within DoD. The JSAM is the single, unifying DoD registry for approved IT and NSS standards and standards profiles that are managed by the Defense Information Systems Agency (DISA). The JSAM baseline lists IT standards that are mandated for use in the DoD acquisition process. The DISR is the standards data source that is used to populate and develop Standards Viewpoints (StdV-1 and StdV-2) that are required artifacts in information support plans (ISP). The complete DISR can be accessed at https://jasm.apps.mil/my.policy. with a DoD Common Access Card (CAC) and registration.

CBM+ implementers should be familiar with the ISO, SAE, IEEE, NSS, MIMOSA, and other 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.

3.2.3.2. 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+ application in DoD, there are a multitude of possible approaches to the 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 organization 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).

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.

3.3 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. Organizations will need to evaluate existing capabilities and limitations such as storage, bandwidth, and cybersecurity. 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 the essential elements of a CBM+ strategy should come together under an operating concept in which weapon systems 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 of 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 compute 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 prognostic 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. Deport 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.

4. CBM+ and the Total System Life Cycle

This section discusses the planning and implementation of CBM+ under the principles of Continuous Process Improvement (CPI)[15]. 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 or implemented into a legacy system.

Through the application of CPI principles, it is envisioned that the elements of CBM+ should be revisited as the life cycle progresses, conditions change, and technologies advance. Another user 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.

Table 6 summarizes the basic steps for planning, implementing, and operating a CBM+ initiative or project.

1.	Understanding that CBM+ is a continuous improvement initiative over the life cycle of a weapon system or equipment.
2.	Ensuring a full understanding of the planning, implementation, and operations phases of CBM+ by the implementation team, functional managers, stakeholders, and customers.
3.	Initiating the CBM+ planning phase and completing the processes needed to develop a CBM+ strategy and to begin the selection of applicable technologies.
4.	Managing the CBM+ implementation phase as a time-phased execution of process changes, technology insertion, organizational realignments, and equipment changes.
5.	In the operations phase, incrementally deploying CBM+ capabilities to operational user locations and continue through full execution of required CBM+ capabilities.
6.	Continuously assessing CBM+ progress and overcoming barriers to successful execution as they occur.
7.	Discontinuing or modifying CBM+ capabilities for specific weapon systems and equipment as requirements evolve with the cessation of use of replacement of those capabilities.

Table 6 - Managing CBM+ across the Life Cycle

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

4.1. 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.

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:

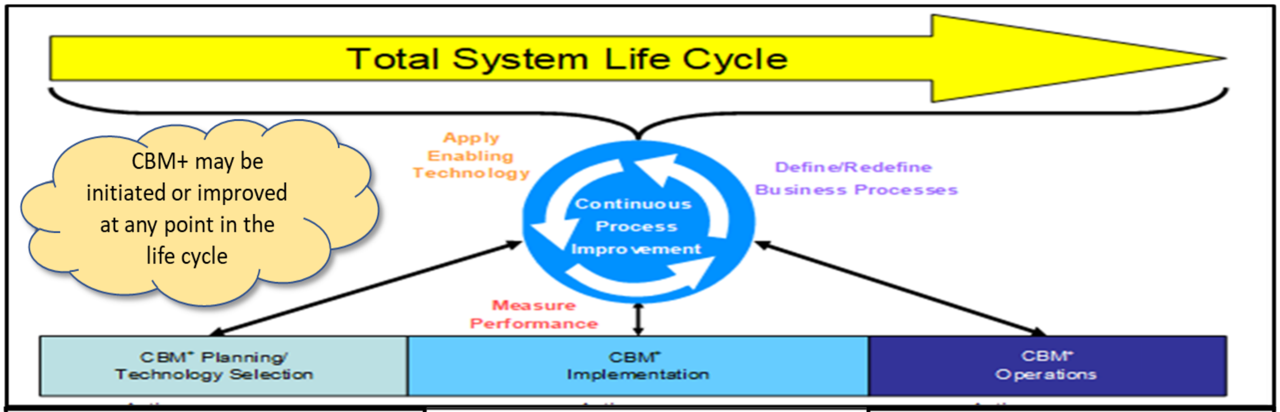
- *Institutionalizing the initiative.* Accomplish actions that create the overarching framework and structure for CBM+, including compliance with DoD policy and guidance.
- *Changing the environment.* Implement actions that focus on changing the technological capabilities and business processes within 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. Actions should look at how to bridge cross-service and utilize integrated IT systems, especially in situations with common platforms, systems, and components.
- *Investment justification.* Accomplish actions that improve the understanding and support of the investment required to achieve the goals of CBM+, compelling business case and readiness analyses for justification support in the PPBE 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.

4.2. CBM+ and the Acquisition Life Cycle

The most effective and efficient maintenance plans are developed using the RCM analysis process as early as possible 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 is slow, this guidebook also 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 cost beneficial, regardless of where the particular weapon system or equipment is in its life cycle. It is desirable that CBM+ implementations be executed in the context of larger perspectives, 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 the complement DoD's total system life-cycle acquisition strategy: the planning please, the implementation phase, and the operations phase. The technology aspects of this phased approach are discussed in Appendix 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, concurrently, or not at all. Figure 17 shows the relationships among the planning, implementation, and operations phases.



Actions	Actions	Actions
• Obtain Management Support • Perform RCM Analysis • Perform Reliability Analysis • Form CBM+ Team • Identify CBM+ Target Application • Accomplish Proof-of-Principle • Prepare Implementation Plan • Examine New Technologies • Develop Data Strategy • Develop Architecture • Set Life-Cycle Metrics • Develop Deployment / Support Strategy • Complete Business Case • Develop Resources Strategy / Budget	• Acquire CBM+ Capabilities (Sensors, Communications, Data Repositories) • Acquire Health Management Software • Demonstrate Data Management Approach • Revalidate RCM Analysis • Revalidate Reliability Analysis • Demonstrate CBM+ Element Interoperability • Demonstrate CBM+ Functionality • Complete Pilot Program Field Test • Resolve Performance and Cost Issues • Train Stakeholders and Users • Revise Implementation Plan • Update Supportability Strategy • Acquire Full Production Capability • Accomplish CBM+ Deployment	• Continuously Analyze Condition Data at All Levels • Revalidate RCM Analysis • Revalidate Reliability Analysis • Develop Performance Baselines • Continuously Review CBM+ Metrics • Refresh Enabling Technologies • Revalidate Human Interfaces • Periodically Update CBM+ Business Case • Continuously Update Resources Strategy & Integrated Budget • Optimize Maintenance Strategies

Figure 17 - CBM+ and the Total System Life Cycle

4.3. 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 and are supportive of CBM+ objectives, understanding the planning requirements, and developing the basic steps required to initiate the effort.

4.3.1. 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 requirement documents and ensure that defense acquisition programs exploit CBM+ opportunities as systems performance requirements during system design and development, and throughout the system's life cycle.

In today's DoD logistics community, knowledge about CBM+ the CBM+ initiative is widespread, training programs exist at different levels, and the DoD is linked together with industry on CBM+ activities. Although logistic managers accept CBM+ (to varying degrees) for potential application in DoD maintenance activities, they are often 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 training and 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.

4.3.2. Perform RCM and Reliability Analysis

A cost-effective implementation to CBM+ must begin with an RCM analysis to determine the applicable and effective maintenance tasks required for the system or equipment. These baseline tasks can then be evaluated to determine whether a CBM+ technology is available to augment or replace the task or tasks. However, the more sophisticated the technology, the more expensive it may be. The increase in sophistication can also result in unforeseen reliability issues. Consequently, a BCA should be performed to validate any CBM+ technology implementation.

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 tradeoffs 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 risk of failure within the defined availability, cost, schedule, weight, power, and volume constraints. While conducting such analyses, tradeoffs must be considered and dependencies must be explored for system maintainability and supportability strategies, including CBM+.

Types or reliability analyses include:

- failure modes and effects criticality analysis, which identifies the ways systems can fail, performance consequences, and the support remedies for system failures,
- fault tree analysis, which assess the critical safety functions within the system's architecture and design, and
- reliability block diagram is a modeling tool that supports the reliability and availability analyses on systems. It is used to compute how component reliability affects overall system failure rates and availability.

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

4.3.3. 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, CBM+ is not a one-dimensional discipline. Bringing in personnel that can focus on only one aspect of CBM+ such as sensor technology or health assessment software will not provide the range of expertise needed for effective implementation.

The CBM+ IPT could 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
- Contracting
- 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, some competencies may no longer be required while other competencies may be required to support implementation.

4.3.4. 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 the insertion of CBM+ enablers in new acquisition programs represents a ‘”low-hanging fruit” opportunity. Embedding sensors and related technologies in the design and production phase of acquisition is usually more feasible and acceptable than retrofitting applications in fielded legacy equipment. Adoption of new methods and integration of new technologies is generally more feasible earlier in the system. As an organization gains experience from the adoption of CBM+ with newer programs, the lessons learned can be readily applied to develop plans for implementing and integrating CBM+ technology on previously fielded weapon systems and equipment.

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

Legacy systems pose substantial challenges to the post-production implementation of CBM+. Three problems that commonly are encountered are:

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

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

4.3.5. Accomplish Proof-of-Principle

Considering the time and funding resources required for CBM+ implementation, it is highly advisable for implementers to accomplish small-scale demonstrations of CBM+ methods and technologies before full-scale implementation. A short-term pilot test that uses equipment likely to be used for later 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.

One of the common pitfalls observed is a consistent pattern of small-scale demonstration without advancement to full-scale implementation. Organizations that conduct the small-scale tests must continuously evaluate how the test is performing, what results are being achieved, what results aren't being achieved, and what modifications can be made to improve the results. Without conducting the analysis as the pilot evolves and making adjustments, it is easy to get stuck in a never-ending loop of pilot initiatives and fail to realize the desired impacts of a full-scale implementation.

4.3.6. 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 leads to required operational and analytic processes, skills, and technologies.
- Requirements statements and planned design approaches for each of the six CBM+ essential elements are 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 which may be developed in greater detail over time.

CBM+ implementation plans may differ from the suggested format above however, a formal implementation plan must be prepared, fully staffed, and approved by the 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 may include contracting approaches, particularly when the CBM+ architectural documentation is completed.

4.3.7. 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 (see 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 the 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.

4.3.8. 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.

Equally important as part of a data strategy is developing a standardized format for the data that is being collected. The use of a standard format will make analysis of the data at an aggregate level easier. Standardized data elements and methods will also help to simplify and streamline the transfer of data between the multitude of systems. Standardized data elements will eliminate confusion as to the ‘meaning’ of a data element between systems and the need for decoder rings to understand during compilation from multiple sources.

4.3.9. Develop Architecture

Once the CBM+ implementation plan has been approved, the IPT should begin constructing the architectural views, descriptions, and profiles as described in 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 the 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 in 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.

4.3.10. 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. The minimum set of life cycle sustainment metrics (sustainment KPPs and KSAs) address in Section 1 of this guidebook should form the starting point. As the implementation effort progresses, additional high-level performance and cost metrics should be developed as well as supporting or diagnostic metrics[16]. Initially however, the CBM+ implementation team should identify which high-level metrics are required to monitor overall maintenance performance, costs, and results.

The CBM+ implementation team should begin with metrics developed through recent research that use the balanced scorecard approach.[17] 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 the individual customers;
- Addressing internal business performance; and
- Addressing process improvement initiative results.

Implementation of CBM+ requires a structured approach to measuring both the progress of implementation and 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.

4.3.11. 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 “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 decision 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

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[16] 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.
[17] Robert S. Kaplan and David P. Norton, “The Balanced Scorecard – Measures that Drive Performance,” *Harvard Business Review*, January – February 1992.

metrics 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.

4.3.12. 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.[18]

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.[19] 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.

4.3.13. 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 weapon systems 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 the 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 PPBE documents. CBM+ managers should ensure validated

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[18] A BCA learning module is available at https://dau.edu/courses/log-0150

[19] A model for developing a CBM+ business case is available at https://www.acq.osd.mil/log/MR/.cbm+.html/CBM+_BCA_Paper.pdf

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 PPBE cycle will minimize diversions of these resources to other competing needs.

4.4 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 requirements for comprehensive objectives setting and rigorous planning prior to the 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 principal activities to be executed during CBM+ implementation.

4.4.1. 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 for obsolescence and availability of technology refreshment provisions are also important, as DoD tends to retain equipment considerably longer than the private sector.

DoD policy requires use commercial-off-the-shelf (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.

4.4.2. Acquire Health Management Software

Software acquisition should be the 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.

4.4.3. 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 definition 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 operations (i.e., user) personnel should occur as early as possible in the implementation phase. This demonstration should include a review of the 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.

4.4.4. 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.

4.4.5. 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, demonstrating proper interaction between the equipment platform and the 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 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.

4.4.6. 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 This end-to-end functionality should be tested according to the CBM+ architecture design.

The demonstration of functionality should assure the CBM+ implementation 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.

4.4.7. 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 the 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 events 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 more controlled than actual operations. The following are among the elements that need to be controlled.

- 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 RCM analysis and reliability analysis are the most appropriate for the tested equipment or component. The DoD has implemented a project management tool where pilot program information can be stored and shared with other CBM+ practitioners.

The COP4ST suite, located within Advana, can be found at: https://wiki.a2et.advana.data.mil/display/ASTECH/Advanced+Sustainment+Technology+Home

4.4.8. 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 the implementation plans. Revise all planning documents based on current management decisions.

4.4.9. 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 with the technology to enable 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 the 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 reduces the demand on the training establishment.

CBM+ implementers should seek out existing CBM+ related training available across DoD (e.g., DAU course CLL-029 CBM+) and commercial industry and make use of this training to the greatest extent possible.

4.4.10. 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, such as DoD policies, 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.

4.4.11. Update Supportability Strategy

Efforts to increase weapon system availability while reducing life-cycle costs and logistics footprints 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.

4.4.12. 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.

4.4.13. 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 the installation of 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.

4.5 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.

4.5.1. 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 operation 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.

4.5.2. 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.

Initial RCM analysis results informed the creation of the maintenance tasks that enabled CBM and the inclusion of appropriate CBM+ enablers. Data gathered from maintenance and other functions should be used to revisit the RCM analysis process and either validate current maintenance strategies or justify adjustments to the plan. This is particularly important over time as equipment ages or is modified, missions change, and technology advances.

4.5.3. 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, as well as 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 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.

4.5.4. 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 at 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.[20] 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, the challenge often 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 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, systemic, 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:

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

- 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 to achieve the organization’s mission.

4.5.6. 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 diagnostics and prognostics 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.
- Use open-source standards and technologies where feasible and cost effective to reduce risk of being tied to sole-source or proprietary hardware and software.
- 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.

CBM+ implementers should understand the downsides to technology refreshment, such as expensive modification and increased configuration management for multiple versions of software and hardware. Include the requirements for planning, programming and budgeting sufficient funds to enable a technology refresh. An updated business case will help support refresh.

4.5.7. Revalidate Human Interfaces

The American culture has strong faith in technology to overcome many obstacles and help with almost any job. It is critical for the CBM+ manager to avoid a mismatch between technology capabilities and the ability of the 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.

4.5.8. 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 is also 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 to the BCA may help fine tune the long-term CBM+ strategy and to provide quantified justification for revised inputs to budget updates.

4.5.9. Continuously Update Resources Strategy and Integrated Budget

As the maintenance strategy for any major acquisition program must include CBM+, it should also be identified and described in the program LCSP. This includes discussion about funding and sustainment over the lifecycle. 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 revies, 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.

4.5.10. 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 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, the 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.

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5. Managing a CBM+ Initiative or Program

5.1. A CBM+ Program Review Checklist

CBM+ planning and implementation may be initiated at any point in the acquisition life cycle from the materiel solution analysis to the operations & support phases. The initiative manager must be prepared to describe, market, and justify the CBM+ strategy and required resources for reviewers, stakeholders, and customers throughout the initiative's entire life cycle. Table 7 is a suggested 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.

Area	Issue
Policy	Is this CBM+ initiative fully consistent with and supportive of DoD and Service policy and direction?
Requirements identification	Is this CBM+ initiative based on approved business needs? Have the strategy and implementation actions been documented in joint requirements documents? Has an RCM analysis been conducted to determine baseline maintenance requirements?
Resources strategy	Have BCAs been completed for each initiative? Have the best-cost funding requirements from the BCA 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 PSS, Performance-Based Acquisition, or Systems Engineering? Does the LCSP describe the CBM+ implementation strategy?
Reliability relationship	Has a reliability analysis and/or an RCM 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 or planned 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? Have cybersecurity requirements been met?
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?
Continuous process improvement	Does the CBM+ implementation strategy fully 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?

Table 7 - CBM+ Program Review Checklist

5.2. 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, goals, 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 (PDCA) model (Figure 18).

Figure 18 - 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 mode work requires substantial and continuous commitment on the part of management. The following are among the management strategies that 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.
- Maintain a flexible, efficient 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 thins 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 an organizational mission.

5.3. CBM+ Relationship 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+ community include the following:

- PSS
- RCM
- Performance-Based Acquisition
- Systems Engineering
- Information Technology Portfolio Management

5.3.1 CBM+ and the Product Support Strategy

Under the DoDs Product Support Strategy, 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 performance requirements at best value to DoD.

PSS 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 the PSS, as shown in Figure 19.

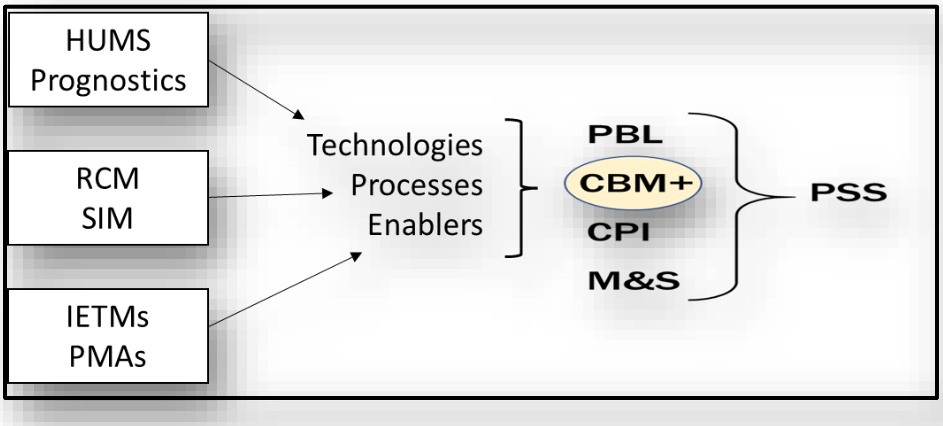

Figure 19 - CBM+ Relationship to PSS

5.3.2. CBM+ and Reliability-Centered Maintenance

RCM is the analytical process used by maintenance managers in determining appropriate maintenance actions when considering costs, accuracy, and availability of required data, and the specific failure mechanism being analyzed. Opting for condition-based maintenance strategies in one possible outcome from 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. Applying RCM and CBM+ will provide maintainers with the rationale for choosing the most technically appropriate and effective maintenance task for a component or end item. In addition, the availability of timely and accurate condition assessment data made available through CBM+ capabilities will support RCM analytical reviews to update applicable approved maintenance requirements throughout the life cycle of the component or end item.

5.3.3. CBM+ and Performance-Based Acquisition

Performance-driven outcomes means the performance of all provider activities is measured against clearly defined outcomes at the weapon system level. Within that context, the performance-based acquisitions strategy is an approach that supports an approach structured around the results to be achieved as opposed to the manner by which the work is to be performed. As CBM+ helps focus the maintenance process on maximizing weapons and equipment readiness with optimum resource allocation, it fully complements the performance-based concept. In fact, it becomes an essential factor in attaining the performance-based objectives in the area of maintenance. DoD policy prescribes performance-based acquisition strategies as the approach that will be applied to all new procurements and upgrades, as well as re-procurements of systems, subsystems, and spares that are procured beyond the initial production contract award.[21] CBM+ tools, technologies, and processes achieve desired outcomes through continuous improvement of weapon system performance and availability, along with a reduction in ownership costs.

5.3.4. 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. PSMs are specifically charged under 10 USC 4324 to "ensure the life cycle sustainment plan is informed by appropriate predictive analysis and modeling tools that can improve material availability and reliability, increase operational availability rates, and reduce operation and sustainment costs"[22]. PMs, PSMs, 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.

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[21] DoD Directive 5000.1, *The Defense Acquisition System,* September 9, 2020, Enclosure 1.

[22] 10 USC 4324

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 that 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 the extent and accuracy that reliability, maintainability, and the necessary tools and information (such as prognostics and diagnostics) have been 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.

5.3.5. 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 organization 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, common data standards, or supporting technology applications. Making full use of joint-use applications will enable CBM+ funding requirements to compete more effectively.

5.4. 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. Appendix C discusses some elements of resistance to change that are likely to be encountered in a CBM+ implementation.

5.5. 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 and execution. A good manager periodically steps back, reviews the organization's process, and assesses the initiative results to date.

As a 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 Life-Cycle Sustainment?
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 and do I have adequate training for the team (e.g., RCM training, CBM+ training)?
5. Does the implementation approach represent the varied interests and objectives of stakeholders and customers?
6. Are the implementation and operating tasks sufficient to cover the breadth of the strategy, and are they tied to a relevant organizational strategic plan?
7. Have I applied Reliability-Centered Maintenance (RCM) analysis to develop initial maintenance requirements?
8. Does the action plan accommodate the requirements, and can it be achieved in a reasonable amount of time?
9. Do the implementation tasks and measures flow directly from applicable operational requirements incorporated into applicable acquisition requirements documents?
10. Does the continuous assessment strategy provide a clear view of the road ahead, and does it point directly to the desired results?
11. Do I have a management approach that is agile and flexible enough to account for changing conditions and environments?
12. 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?
13. Have I identified promising implementation alternatives in response to resource changes?
14. Have I found any breakthrough capabilities, and can I describe practical uses for them?
15. Have I developed a capabilities-based BCA with defendable results based on readiness objectives and best cost?
16. Are the resource estimates, based on the affordability and technical feasibility, of my planned implementation approach included in an integrated budget submission reasonable?
17. Do I have a good architectural framework?
18. Have I generated a compelling set of actions for each implementation milestone that fives decision makers a real set of options?

19. Have I identified excess capabilities resulting from CBM+, and do I have an organization plan for bringing them forward?
20. Have I developed a prudent technology refreshment strategy to upgrade CBM+ components ahead of the obsolescence curve?

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6. Measuring Success

Metrics are an important element in measuring the success of any program. Metrics provide an objective evaluation and allow program managers to determine if their efforts are yielding the desired results or if changes are necessary. Table 8 summarizes the basic characteristics for identifying, collecting, and using key metrics for effectively measuring the implementation and operation aspects of CBM+.

1. Are selected metrics imposed on the organization that controls the processes producing and tracking the metric?
2. Do the users (i.e., management, customers, and stakeholders) accept the selected CBM+ metrics as meaningful?
3. Do the metrics show how well the goals and objectives are being met through CBM+ processes and tasks?
4. Do the selected metrics measure something useful (valid), and measure it consistently over time (reliable)? Do they reveal a trend?
5. Are the 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? Is the metric 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?

Table 8 - Measuring Success Checklist

There is no shortage of data available to management in DoD information systems. One of the problems the department faced with large amounts of data was where to find the relevant information and how to bring it all together meaningfully. In 2019, the DoD began an effort to bring the data from thousands of disparate systems together into a single repository, and thus Advana was created. The Advana environment collects data from the multitude of Service level systems to provide a single source where data across the department can be extracted and evaluated. An additional benefit is that Advana enabled each Service to create its own data store within the Advana environment simplifying access to their specific data as well. As the CBM+ community continues its journey, the importance of being able to use and act upon Advana data cannot be understated.

Data collected typically falls into one of three categories: workload; current resource expenditure and outputs; and performance compared to established standards and goals. CBM+ implementers should seek to identify metrics that will give program managers and operators a consistent and quantifiable picture of maintenance performance and related costs.

Although no single set of performance metrics 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 teams will use those metrics to help form the initiative and ultimately manage the CBM+ maintenance capabilities that will deliver the required level of performance in future logistics operations. Metrics for CBM+ will fall into two categories:

- Implementation metrics
- Operating metrics.

6.1. Implementation Metrics

6.1.1. 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 just 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 9.

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.	
Communication	Implement databases and off-board interactive communication 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, self-assessment, analysis, decision-support execution and recovery, both on- and off-board.	

Table 9 - A CBM+ Capability Scorecard

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 10 is an example of such a checklist, but it should be tailored to fit your particular circumstances.

Progress Element	Evaluation Criteria
Management Support	Statements of support Approval of projects documented Ideas / inputs provided Successes praised and publicized
Team Building / Program Initiation	Understanding of concepts by employees Training programs completed Policy and CBM+ requirements reviewed Skills from training used Projects actively supported Ideas and feedback provided
Understanding the Process	Processes, systems, and resources documented Architecture diagrams developed Applicable technologies identified Metrics system implemented
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

Table 10 - Internal Progress Evaluation Criteria

6.2. Operating Metrics

6.2.1. How to Measure a Maintenance Program Operating in a CBM+ Environment

CBM+ empowers the Services and PMs to pursue maintenance process improvement and technology to support the operational warfighter more effectively. 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 well 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 for Acquisition and Sustainment (A&S) has established policy for the selection of metrics applicable to logistics activities. 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 modeling and simulation 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.

6.2.2. Relevant Operating Metrics for CBM+

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

- Material 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 the mean down time of equipment.

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

6.2.2.1. 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 have a maintenance component that could be affected by CBM+ improvements. Some related metrics include the following:

- Mission capable rates – operational availability – currently reported in the 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.

6.2.2.2. 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 availability is generally expressed in terms of a mean time between failure (MTBF). Once operational, it can be measured by dividing the actual operating hours by the number of failures experienced during a specific interval.

6.2.2.3. Reducing Life Cycle Ownership Costs

DoD 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 proposed metric the 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 the permit comparison of cost of maintenance labor and parts over time.

6.2.2.4. 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.

6.3. 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 (e.g., 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 process 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 PSS (quarterly) metric;
    - Depot maintenance-related MTBF – same as above;
    - MDT – proposed PSS (quarterly); and
    - Equipment availability – available quarterly through the QRRC and as required through GSORTS.
- Number of repairs accomplished at field / intermediate level versus return to depot for repair / overhaul.

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Appendix A.
Definitions

Term	Definition
AIS	A system of computer hardware, computer software, data, or telecommunications that performs functions such as collecting, processing, storing, transmitting, and displaying information. AISs are the information processors that accept, process, store, and pass AIT data.
AIT	A suite of technologies that automatically captures data, thereby enhancing the ability to identify, track, document, and control assets (e.g., materiel) and deploying and redeploying forces, equipment, personnel, and sustainment cargo. AIT encompasses a variety of data storage or carrier technologies, such as linear bar codes, two-dimensional symbols, magnetic strips, integrated circuit cards, optical laser discs, or satellite tracking transponders and radio frequency transponders.
condition-based maintenance	A maintenance practice based on monitoring the condition of equipment to assess whether it will fail during some future period in order to take appropriate action to avoid the consequences of that failure. Condition-based maintenance employs real-time or approximate real-time assessments of data obtained from the equipment or external tests and measurements using either test equipment or actual inspection. The objective of condition-based maintenance is to perform maintenance based on the evidence of need while ensuring safety, reliability, availability, and reduced life-cycle cost.

Term	Definition
CBM+	A collaborative DoD readiness initiative focused on the development and implementation of data analysis and sustainment technology capabilities to improve weapon system availability and achieve optimum costs across the enterprise. 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. CBM+ is built upon RCM and condition-based maintenance to enhance safety, increase maintenance efficiency, improve availability, and ensure environmental integrity. CBM+ diminishes life-cycle costs by reducing unscheduled maintenance and enabling predictive maintenance. CBM+ turns rich data into information about component, weapon system, and fleet conditions to more accurately forecast maintenance requirements and future weapon system readiness to drive process cost efficiencies and enterprise activity outcomes.
CBM+ data	At its core, CBM+ is performing maintenance based on the evidence of need. That "evidence" is provided through the collection and aggregation of accurate data and analysis. This data includes life cycle item management data as well as environmental data and data from embedded sensors. CBM+ data is captured from the equipment item in a variety of methods which may include physical inspection, capture of recorded maintenance and supply event data as well as real-time data collection from embedded sensors on military equipment.

Term	Definition
CBM+ tools and technologies	The complement of tools and technologies used as enabling capabilities needed to execute CBM+ strategies and plans. Examples of these tools and technologies include but are not limited to: embedded sensors, data aggregation and storage capabilities, automatic identification technologies, portable maintenance aids, integrated information systems, artificial intelligence and machine learning, and automated test equipment.
corrective maintenance	Corrective maintenance consists of the necessary actions to restore a system or component after a failure has occurred.
diagnostic maintenance	Diagnostic maintenance is the process of identifying and resolving problems with a system or component. If involves the use of specialized tools to detect and diagnose faults or irregularities, and take corrective action to fix them.
IUID	The application and use of a unique item identifier as the global common data key in financial, property accountability, acquisition, and logistics (including supply and maintenance) automated information systems to enable asset accountability, valuation, lifecycle management, and counterfeit material risk reduction.
life cycle item management data	Item-related data that supports product life-cycle management and spans an item's complete life cycle. It begins with initial design, specifications, manufacturing, and acquisition data that include use, supply, accountability, custody, ownership, valuation, sustainment cost, warranty, modification, configuration, reliability, availability, maintainability, performance, and maintenance history data collected in various automated information systems. Relevant maintenance, logistics, and acquisition data supports analysis on specific populations and on each item throughout its life cycle.

Term	Definition
predictive maintenance	Predictive maintenance is a technique to predict the future failure point of a component, so that the component replacement can be planned at an optimal time before it fails. Predictive maintenance differs from preventive in that it uses collected data to determine the condition of the component and forecasts the need for maintenance.
preventive maintenance	Preventive maintenance is a technique where maintenance actions and the replacement of components is based on calendar time, operating time, or some other periodic measurement. Intervals are determined based on engineering reliability and maintainability analyses, reliability centered maintenance and historic failure data.
prognostic maintenance	Prognostic maintenance utilizes the process of forecasting the time to failure. Time left before observing a failure is described as remaining useful life (RUL).
RCM	A logical structured process for determining maintenance requirements based on the analysis of the likely functional failures of components, equipment, subsystems, or systems having a significant impact on safety, operations, and life-cycle cost. RCM supports the failure-management strategy for any component, equipment, subsystem, or system based on its inherent reliability and operating context.
SIM	Programs and techniques that use life-cycle item management data to track the performance of uniquely identified items throughout their life cycle. The overarching goals of these programs and techniques is to enable managers to achieve optimum weapon system materiel availability at the best total ownership cost through effective and efficient life-cycle management practices.

Appendix B.
Acronyms

AIS	Automated Information System
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
DoDAF	Department of Defense Architectural Framework
DoDD	Department of Defense Directive
DoDI	Department of Defense Instruction
DoDM	Department of Defense Manual
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
IUID	Item Unique Identification
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	Mead Down Time
MIL-STD	Military Standard
MIMOSA	Machinery Information Management Open Systems Alliance
MTBF	Mean Time Between Failure
O&S	Operations and Support
OC	Ownership Cost
OSA	Open System 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

R&M	Reliability and Maintainability
RCM	Reliability-Centered Maintenance
S&RL	Sense and Respond Logistics
SAE	Society of Automotive Engineers
SIM	Serialized Item Management
SV	Systems View
TLCSM	Total Life-Cycle System Management
TV	Technical View
USD(A&S)	Under Secretary of Defense for Acquisition and Sustainment
V&V	Validation and Verification
VAMOSC	Visibility and Management of Operating and Support Costs

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Appendix C.
References and Resources

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

DoD Technology Related Resources

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

Air Force Research Laboratory, https://afrl.af.mil

Army Research Laboratory, https://arl.army.mil

Defense Acquisition University, https://www.dau.edu

Defense Advanced Research Project Agency, https://www.darpa.mil

Defense Technical Information Center, http://discover.dtic.mil

National Center for Manufacturing Sciences, https://www.ncms.org/

Navy Research Laboratory, https://mrl.navy.mil

Quanterion Solutions Incorporated, https://www.quanterion.com/

Condition-Based Maintenance Plus Guidebook

Office of the Under Secretary of Defense for Acquisition and Sustainment
3030 Defense Pentagon
Washington, DC 20301
OSDAS-COP4ST@groups.mail.mil
https://www.acq.osd.mil/log/MR/cbm+.html