**DEPARTMENT OF THE NAVY**
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MARINE CORPS ORDER 4151.22

From: Commandant of the Marine Corps

To: Distribution List

Subj: CONDITION BASED MAINTENANCE PLUS (CBM+) ORDER

Ref: See enclosure (1)

Encl: (1) References
(2) CBM+ Guidebook

1. Situation. To support current and future operating concepts, our expeditionary logistics enterprise must support and sustain smaller, more lethal units from far greater distances across a dynamic and fully contested battlespace. In this operating environment, conducting timely, effective repairs to ensure that equipment remains continuously combat ready has become increasingly complex. Additionally, facilities and equipment on our installations, which serve as deployment platforms and operating locations from which to fight, have become increasingly complex, expensive to maintain, and degraded. To meet the challenges of this operating environment, Marine Corps units and organizations must be able to predict when maintenance will be required to ensure operational availability of combat essential equipment, optimize utilization of facilities, and reduce cost. Achieving this predictive capability requires a mature Condition Based Maintenance Plus (CBM+) program. Per the references, this Order defines the policies associated with implementing CBM+ within the Marine Corps. This Order is in accordance with references (a) through (t) located in enclosure (1).

2. Mission. Implement CBM+ in order to integrate predictive maintenance capabilities to increase operational availability and decrease life cycle costs, enhancing lethality and support the Marine Air-Ground Task Force (MAGTF) mission.

3. Execution

a. Commander's Intent and Concept of Operations

(1) Commander's Intent. Achieve the total force implementation and integration of CBM+ concepts throughout the integrated total life cycle framework. This Order will leverage people, processes, and technologies to integrate CBM+ and Reliability Centered Maintenance (RCM) within the Marine Corps' maintenance program to increase operational availability and support to the warfighter. CBM+ includes both hardware and software components. The hardware component is associated with Principle End Items (PEIs), capable of monitoring, collecting, and transmitting system data. The software component analyzes PEI system data to adjust maintenance actions founded on the

physical condition of individual assets and subsystems based on both their current condition and planned operational employment. Successful implementation is reliant on data collection and information management practices implemented in accordance with reference (g), and technologies that will provide operational planners, operators, maintainers, maintenance managers, and program managers the right information to maximize the operational availability of MAGTF's PEIs. ENDSTATE: Increase military equipment operational availability, align enterprise integration goals and objectives, and increase readiness of MAGTF resources available to support Fleet Marine Force Commanders.

(2) Concept of Operations

(a) Scope. This Order applies to ground, aviation ground support (AGS), and facilities support organizations. It encompasses Department of Defense (DoD) compliant principles and procedures for the implementation and management of CBM+ by doing the following:

1. Implementing CBM+ per the CBM+ definition outlined in reference (b) and the guidance detailed in this Order.

2. Using CBM+ as a principal consideration in the research and development of new maintenance concepts, enabling technologies, and processes for all new weapon systems, equipment, and materiel programs based on operational availability, lifecycle cost goals, and RCM-based functional analyses formulated in a comprehensive Reliability and Maintainability (R&M) engineering program.

3. Including CBM+ requirements in the development of mandatory sustainment Key Performance Parameters (KPP) and supporting Key System Attributes (KSA) in accordance with reference (m) for Acquisition Category I (ACAT I) programs.

4. Including CBM+ requirements in the development of sustainment KPPs, KSAs, or sponsor defined sustainment metrics in accordance with reference (m) for Acquisition Category II (ACAT II) and below programs.

5. Prioritizing resources for implementation of CBM+, including product development, procurement, and sustainment.

6. Integrating CBM+ technologies in current weapon systems, equipment, and materiel sustainment programs where it is technically feasible, improves materiel availability, and is cost-effective.

7. Incorporating CBM+ language and requirements into maintenance concepts and into contracts for systems and programs supported in organic or commercial sectors.

8. Measuring for success using materiel availability and operational availability as metrics of the sustainment KPP, and reliability and operational cost as the supporting KSAs.

9. Including CBM+ language in the requirements development process which will establish a mechanism for development documents to drive acquisition actions.

(b) The following concepts are established by DoD and directed to be implemented within Service maintenance strategies. Reference (p) integrates these concepts:

1. Condition Based Maintenance Plus (CBM+). CBM+ is the application and integration of processes, technologies, and knowledge-based capabilities to achieve target availability, reliability, and operation and support costs of Marine Corps' systems and components across their lifecycle.

a. The goals of CBM+ are: to perform maintenance only upon evidence of need that is provided through RCM analysis, to increase equipment availability by identifying the optimum opportunity to perform required maintenance, and to optimize the resources used to conduct maintenance. This strategy shifts equipment maintenance from an unscheduled, reactive approach to a more proactive and prognostic approach.

b. To be most effective, CBM+ requires processes, technology, and capabilities that support RCM analysis and maintenance decision-making. These requirements may include but are not limited to: (1) Automated Information Systems (AIS) for maintenance data collection and process analysis, (2) sensors embedded within equipment platforms to provide operators, crew and maintainers enhanced visibility of equipment condition, and (3) portable equipment to conduct external tests and measurements to support RCM analysis. Accordingly, the Marine Corps will acquire or develop Automatic Identification Technology (AIT) and other test, measurement, and diagnostic equipment, and integrate it with existing and emerging AIS to automate and enhance data collection and sharing to support CBM+.

2. Reliability Centered Maintenance (RCM). RCM is a standardized analysis process that assesses operational and maintenance data to enable decisions that improve design, operational capability, and equipment readiness. RCM is used to develop failure management strategies that should be applied to ensure a system achieves the desired levels of safety, reliability, environmental soundness, and operational readiness in the most cost-effective manner. The RCM philosophy employs maintenance strategies such as Preventive Maintenance, CBM, Run-To-Failure (RTF), also called reactive maintenance, and proactive maintenance techniques in an integrated manner to increase the probability that a platform or component will function in the required manner over its design lifecycle with minimal maintenance. In execution, RCM involves performing only those maintenance tasks that will reduce the probability or consequence of a failure, based upon analysis of each failure mode (the specific condition causing the failure) and the consequence of failure (how the failure matters in terms of safety, operational capability of the equipment, etc.). Per direction provided to all military departments in reference (b), RCM will be incorporated into maintenance planning and integrated with systems engineering processes. Doing so will improve maintenance tasks and schedules over time as maintainers identify root cause failures and increase their knowledge of system performance through analysis of equipment usage and maintenance data. The results will be a predictive maintenance capability that increases reliability, availability and maintainability of equipment.

b. Subordinate Element Missions. The Marine Corps Total Force and supporting establishments responsible for research and development, acquisitions, associated life-cycle management, logistics, informal and formal weapon systems, and equipment training will ensure that the provisions of this Order are effected in the administration of the Marine Corps maintenance and maintenance management programs. Specific responsibilities for CBM+ stakeholders are as follows:

(1) Deputy Commandant, Installations and Logistics (DC I&L)

(a) Serve as the Total Life Cycle Management (TLCM) Chair per reference (p). Lead the Ground Enterprise execution for CBM+ concept implementation and ensure the roles and responsibilities identified in this Order are adhered to by the appropriate stakeholders to achieve and maintain strict equipment availability, visibility, and supportability.

(b) Serve as the functional advocate for logistics and installations information systems that support TLCM. Ensure these systems are available and effective to enable CBM+ of ground and facilities equipment.

(c) Leverage an oversight body of cross-functional interest to govern CBM+ equities, including but not limited to requirements development, acquisition, resourcing, and sustainment.

(d) In partnership with applicable stakeholders, identify and obtain required resources through the planning, programming, budgeting, and execution (PPB&E) process to fully implement CBM+ for ground equipment.

(e) Advocate for CBM+ doctrine development and training and education programs with Commanding General, Training and Education Command (CG TECOM).

(f) Ensure all maintenance related policies are consistent with CBM+ methodologies.

(g) Coordinate with Deputy Commandant, Information (DC I) to establish and sustain an enterprise CBM+ solution architecture that can be integrated with other Services, the Joint Logistics Enterprise (JLEnt), and partner repositories.

(h) Coordinate with Deputy Commandant, Combat Development and Integration (DC CD&I) and advocate for CBM+ capabilities and resource requirements in the Joint Capability Integrated Development System (JCIDS) process for all new equipment, weapon systems, and information systems.

(i) Coordinate with DC CD&I; Deputy Commandant, Programs and Resources (DC P&R); and Deputy Commandant, Plans, Policies, and Operations (DC PP&O) to prioritize CBM+ implementation across applicable platforms.

(j) Lead development of CBM+ business processes and information exchanges and ensure they are reflected in the Logistics and Installations Enterprise Architecture.

(k) Coordinate with Commander, Marine Corps Systems Command (COMMARCORSYSCOM) / Program Executive Officer Land Systems (PEO-LS) and Deputy Assistant Secretary of the Navy for Sustainment (DASN-S) to implement metrics to measure the effectiveness of CBM+ and platform-embedded health management systems.

(l) Participate in appropriate acquisition lifecycle events, reviews, and assessments to ensure compliance with CBM+ objectives described in this Order.

(m) Coordinate with MARCORSYSCOM/PEO-LS to utilize an array of tools such as modeling and simulation capability that can validate CBM+ functionality and the effectiveness of platform health management systems.

(n) Develop standards that use common CBM+ terminology for integrated platform health management across all weapon systems.

(2) Deputy Commandant, Aviation (DC AVN). Advocate for the implementation of CBM+ technologies, methodologies, and adequate resources for all aviation ground equipment and aviation ground support equipment.

(3) Deputy Commandant, Combat Development and Integration (DC CD&I)

(a) Leverage study and experimental results to contribute to the development of CBM+ enablers for materiel development decisions.

(b) Evaluate CBM+ technologies, guide science and technology programs, advanced component development, and prototype programs during the requirements development process.

(c) Conduct Doctrine, Organizations, Training, Materiel, Leadership and Education, Personnel, and Facilities (DOTMLPF) gap analysis and integrate CBM+ methodologies and technologies, as determined by the DOTMLPF analysis, into existing programs of record.

(d) Ensure Technology Readiness Level 6 or greater is assessed for CBM+ capabilities and written in the Capability Development Document (CDD).

(e) Ensure CBM+ solution concepts are designed to enable the attainment of the Sustainment KPP.

(4) Deputy Commandant, Program and Resources (DC P&R). Resource requirements through the Program Objective Memorandum process to support CBM+ capabilities.

(5) Deputy Commandant, Plans, Policies, & Operations (DC PP&O). Participate in forums requiring equipment lifecycle maintenance, planning, and execution of weapon systems, equipment, and materiel.

(6) Deputy Commandant, Information (DC I)

(a) In coordination with DC I&L, issue policy and guidance on the usage of approved information technology architecture to support CBM+.

(b) Review and approve IT architecture, including cybersecurity requirements, prior to investment and ensure adequate information resources are applied to sustain capabilities in support of CBM+.

(c) Ensure integration of current and future technologies supporting voice, video, and data services leveraging available interoperable, secure, and highly available communication network infrastructure in support of CBM+.

(d) Provide policy for interfacing applications and components to the Marine Corps Enterprise Network (MCEN).

(7) Commanding General, Marine Corps Logistics Command (CG MARCORLOGCOM)

(a) Utilize CBM+ data to ensure CBM+ capabilities are included in depot maintenance lifecycle cost.

(b) Leverage CBM+ in current and future depot-level maintenance.

(c) As the Marine Corps' executive agent for Enterprise Lifecycle Maintenance Process (ELMP), coordinate with all the relevant Marine Corps' TLCM stakeholders to develop CBM+ requirements for depot maintenance execution planning.

(d) Provide recommended changes or updates to program offices for product lifecycle support plans that incorporate implementation of CBM+.

(e) Provide data, information, and reports for supportability assessments, strategy development, planning, and business case analyst studies in support of CBM+ implementation.

(8) Commander, Marine Corps Systems Command (COMMARCORSYSCOM)/Program Executive Officer Land Systems (PEO LS)

(a) Consistent with Assistant Secretary of the Navy (Research, Development, and Acquisition) programmatic oversight authorities per reference (h), ensure Milestone Decision Authorities (MDA) appropriately consider implementation of CBM+ technologies and methodologies.

(b) Conduct a Reliability Centered Maintenance Analysis (RCMA) and other maintainability and supportability analyses where applicable on existing and new acquisition platforms to enable integration of CBM+ technologies and methodologies.

(c) Conduct comprehensive materiel reviews and assessments that optimize life cycle logistics integrated product support element processes and activities (including updates to applicable technical manuals) that will expedite repair and support processes consistent with existing and emerging CBM+ maintenance practices.

(d) Ensure personnel responsible for the acquisition, design, development, demonstration, deployment, and sustainment of Marine Corps ground equipment are trained and educated on CBM+ technologies and methodologies.

(e) Maintain resident expertise in RCM and CBM+ to enable PMs to use RCM and CBM+ for Total Life Cycle System Management (TLCSM) decisions across the equipment lifecycle. Provide expertise supporting initial implementation and sustained execution of RCM and CBM+ processes in new and legacy weapon systems.

(f) Support continual improvement and advancements of CBM+ concept technologies, applicable support equipment and computer resources across all affected integrated product support elements for the materiel solution product support strategy through its full useful life.

(g) Advise stakeholders on CBM+ concepts related initiatives/ activities to include identification of investment costs, product improvements, and potential savings impacting force design, development, and management to achieve warfighting requirements.

(g) Ensure DC I&L is included in appropriate acquisition lifecycle events, reviews, and assessments to ensure compliance with CBM+ objectives described in this Order.

(h) Identify life cycle sustainment challenges through examination, evaluation, use, and implementation of CBM+ solutions from public and private sources as appropriate to deliver sustainability KPPs and availability KSAs of new and fielded materiel where suitable, sustainable, and affordable to deliver defined requirement capabilities.

(9) Commanding General, Training and Education Command (CG TECOM)

(a) Incorporate CBM+ concepts and methodologies into appropriate training and education curriculums.

(b) Include CBM+ tenets in appropriate Service doctrinal publications.

(10) Commander, Marine Corps Installations Command (COMMCICOM)

(a) In coordination with installations and regions, through the existing communications infrastructure requirements processes, plan for sufficient network bandwidth, communication resources, and infrastructure for Marine Corps tenants in support of CBM+ at Marine Corps installations.

(b) Include CBM+ requirements from installation tenants, and from program level headquarters into facility requirements development, installation master planning efforts, and for subsequent consideration at the Marine Corps Installations and Infrastructure Investment Board (MCI3B), the Capital Investment Working Group, and the Program Objective Memorandum Working Group for prioritization, support, and funding.

(c) Incorporate CBM+ methodologies into installation processes, planning, and development.

(11) Commanders, Marine Corps Forces (COMMARFOR)

(a) Ensure that this Order is made available, understood, and used by all personnel responsible for the use and implementation of CBM+.

(b) Commanders at all levels shall use the CBM+ philosophy and amplify the importance in command policies in order to sustain equipment.

(c) Direct subordinate commands to develop and implement internal command policies and procedures to facilitate the execution of this Order.

(d) Participate in the JCIDS process by providing subject matter expertise to register CBM+ requirements.

(e) Ensure subordinate units are collecting and transmitting data in support of CBM+ requirements.

c. Coordinating Instructions

(1) All subordinate elements tasked within this Order provide representation to the CBM+ oversight body as required.

(2) Coordinate updates to this Order with DC I&L.

4. Administration and Logistics

a. Recommendations concerning the contents of this Order are invited and should be submitted to Assistant Deputy Commandant, Installations and Logistics (LP) attention to Logistics Policy and Capabilities Branch via the appropriate chain of command.

b. Records Management. Records created as a result of this Order shall be managed according to National Archives and Records Administration (NARA) approved dispositions per reference (m) to ensure proper maintenance, use, accessibility and preservation, regardless of format or medium. Records disposition schedules are located on the Department of Navy/Assistant for Administration (DON/AA), Directives and Records Management Division (DRMD) portal page at: https://portal.secnav.navy.mil/orgs/DUSNM/DONAA/DRM/Records-and-Information-Management/Approved%20Record%20Schedules/Forms/AllItems.aspx. Refer to reference (s) for Marine Corps records management policy and procedures.

c. Privacy Act. Any misuse or unauthorized disclosure of Personally Identifiable Information (PII) may result in both civil and criminal penalties. The Department of the Navy (DON) recognizes that the privacy of an individual is a personal and fundamental right that shall be respected and protected. The DON's need to collect, use, maintain, or disseminate PII about individuals for purposes of discharging its statutory responsibilities shall be balanced against the individuals' right to be protected against unwarranted invasion of privacy. All collection, use, maintenance, or dissemination of PII shall be in accordance with the Privacy Act of 1974, as amended (reference (p)) and implemented per reference (k).

5. Command and Signal

a. Command. This Order is applicable to the Marine Corps Total Force as defined to ground, Aviation Ground Support (AGS), and facilities support organizations.

b. Signal. This Order is effective the date signed.

C. G. CHIAROTTI
Deputy Commandant,
Installations and Logistics

DISTRIBUTION: PCN 10204390600

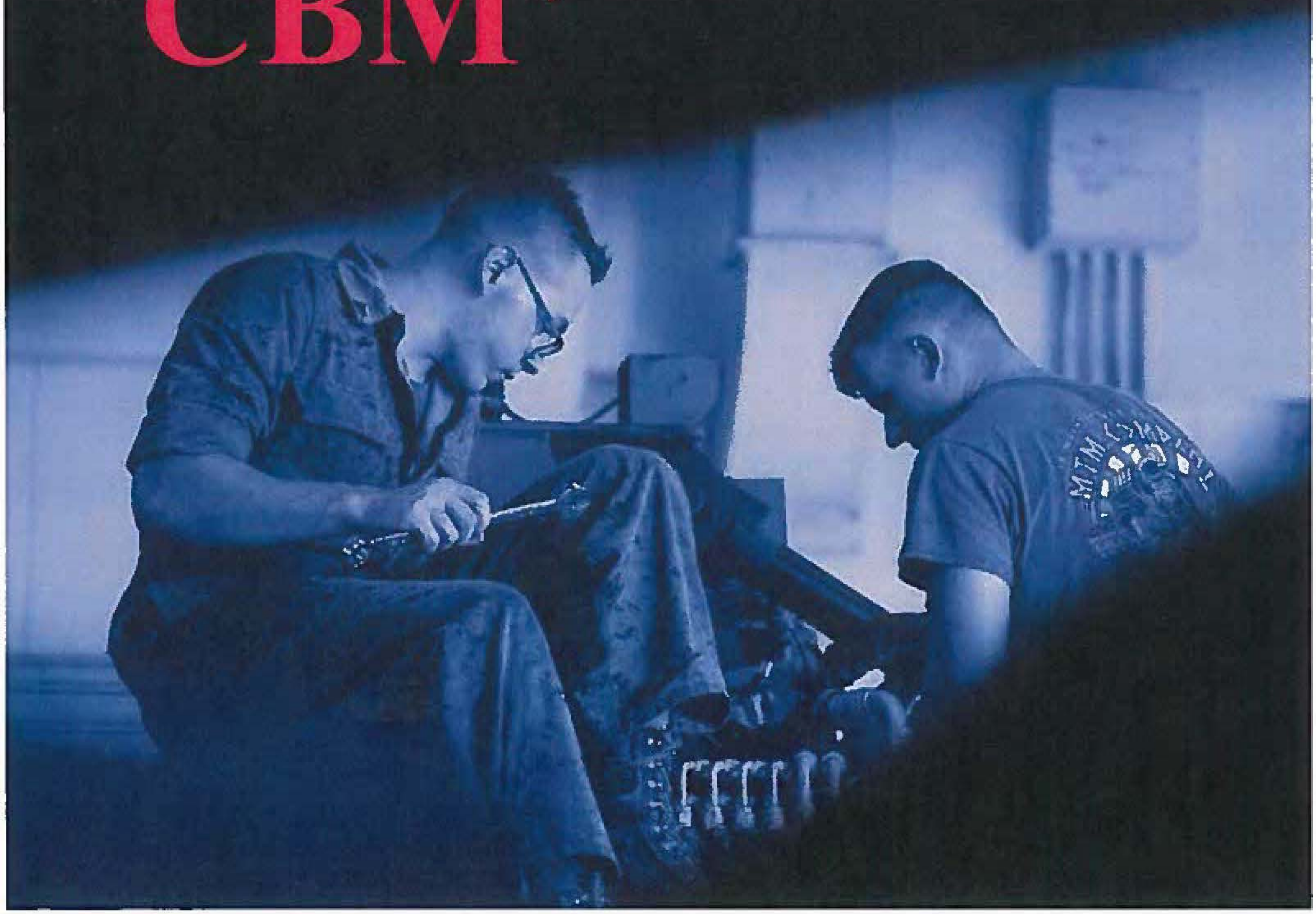
References

(a) DoDD 4151.18, "Maintenance of Military Materiel," 31 March, 2004
(b) DoDI 4151.22, "Conditioned Based Maintenance Plus for Materiel Maintenance," 16 October, 2012
(c) DoDI 3110.05, "Readiness-based Materiel," 25 September, 2006
(d) DoDI 5000.75, "Business Systems Requirements and Acquisition," 2 February, 2017
(e) Condition Based Maintenance Plus DoD Guidebook," May, 2008
(f) DoDM 4151.22-M, "Reliability Centered Maintenance (RCM)," 30 June, 2011
(g) DoDM 8910.01, Volume 1, "DoD Information Collections Manual," 30 June, 2014
(h) MIL-STD-3034A, "Department of Defense Standard Practice: Reliability Centered Maintenance (RCM) Process," 29 April, 2014
(i) SECNAVINST 5000.02, "Acquisition and Capabilities Handbook" 8 December, 2008
(j) SECNAVINST 5400.15C CH-1, "Department of the Navy Research and Development, Acquisition, Associated Life-Cycle Management, and Logistics Responsibilities and Accountability," 2 December, 2011
(k) SECNAVINST 5211.5F, "Department of the Navy Privacy Program", 20 May, 2019
(l) SECNAVINST M-5216.5 CH-1, "Department of the Navy Correspondence Manual," 16 May, 2018
(m) SECNAV M-5210.1 CH-1, "Department of the Navy Records Management Program," September, 2019
(n) OPNAVINST 4790.16B, "Condition Based Maintenance Plus Policy," 1 October, 2015
(o) CJCSI 5123.01H, "Charter of the Joint Requirements Oversight Council (JROC) and Implementation of the Joint Capabilities Integration and Development System (JCIDS)," 31 August, 2018
(p) 5 U.S.C. 552a, "Records Maintained on Individuals"
(q) MCO 4000.57A, "Marine Corps Total Life Cycle Management (TLCM) of Ground Weapon Systems, Equipment and Material," 23 December, 2009
(r) MCO 4790.25, "Ground Equipment Maintenance Program (GEMP)," 12 January, 2014
(s) MCO 5210.11F, "Marine Corps Records Management Program," 7 April, 2015
(t) MCO 3900.20, "Marine Corps Capabilities Based Assessment," 27 September, 2016

DEPARTMENT OF THE NAVY · UNITED STATES MARINE CORPS

# Condition-Based Maintenance Plus Guidebook

# CBM$^+$



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**Figures**

# Introduction

This guidebook supplies basic information about condition-based maintenance (CBM) and condition-based maintenance plus (CBM$^+$). It is intended for those who want to learn more about what CBM$^+$ is, why the U.S. Marine Corps (USMC) is implementing it, and how to measure its success. This guidebook serves to inform its readers of the tenets of CBM$^+$ and guide project development and implementation. CBM, in simple terms, is maintenance when need arises. Imagine OnStar for weapons platforms. Implementation of CBM$^+$ is mandated at the highest levels of the Department of Defense (DoD) and all the military services are at some level of implementation as of this writing.

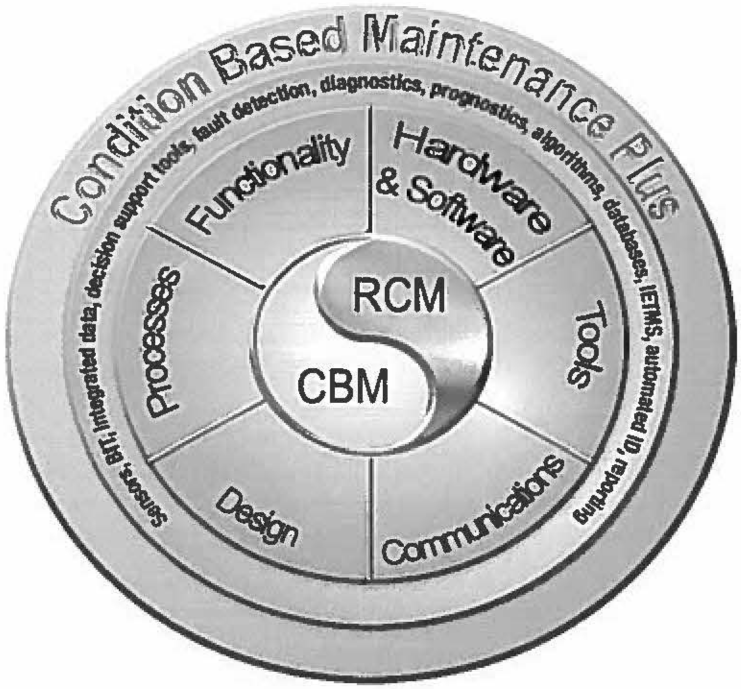



**Figure 1.—Condition Based Maintenance Plus**

This guidebook will furnish information on the following areas:

1. An Introduction to Maintenance Strategies
2. Condition-Based Maintenance Plus
3. Reliability-Centered Maintenance (RCM)
4. DoD and Marine Corps Policies
5. Fundamental Elements of CBM$^+$
6. Systematic and Incremental Implementation of CBM$^+$
7. Measuring Success.

This *CBM$^+$ Guidebook* is about performing maintenance in a different way than the Marine Corps does today. CBM$^+$ will require many changes to maintenance businesses processes. Today, the Marine Corps performs scheduled maintenance—the practice of maintaining equipment on a regular schedule based on elapsed time or counter reading. With CBM-enabled platforms, maintainers no longer perform routine scheduled maintenance, but instead perform maintenance based on evidence of need. Evidence of need is data, research, or other form of appropriate evidence collated to demonstrate the demand or need. This new maintenance practice affects maintenance business processes and the supply chain. Sensor data is transformed into actionable fault information transported across the network in real time to maintainers. Historical data is collected to inform fleet managers and intelligent decision support systems analyze large amounts of data to improve prediction algorithms.

$CBM^+$ maintains the correct equipment at the right time by using real-time data to prioritize and optimize maintenance resources. A CBM-enabled system acts only when maintenance is necessary. Developments in recent years have enabled extensive instrumentation of platforms and, together with better tools, such as artificial intelligence for analyzing condition data, the Marine Corps will perform at the right time on a piece of equipment. Ideally, $CBM^+$ will enable maintenance personnel to do only the right things, minimizing spare parts cost, system downtime, and time spent on maintenance.

# Chapter 1
# An Introduction to Maintenance Strategies

## *Definition of a Maintenance Strategy*

The two main categories of maintenance are reactive (also called corrective maintenance) and proactive. These two approaches cover the full spectrum of available maintenance options (see Figure 2). On the extreme end of the reactive side of the spectrum is run-to-failure, which is unscheduled and occurs when a system or component breaks. The next level of maintenance is scheduled maintenance, also called preventive maintenance, which occurs based on predetermined intervals, for example, getting oil changed every three months or every 3,000 miles. These intervals are based on average historical failure rates or engineering estimates, not on specific conditions driven by environmental and operational factors. Preventive maintenance does not account for unexpected failures and falls short of a predictive strategy triggered by assessment of actual equipment condition. Condition-based maintenance takes advantage of certain enablers to schedule maintenance based on real-time trend analysis of the system or platform (diagnostic), or more sophisticated prognostics software that predicts when a predetermined failure threshold will be crossed, initiating a proactive approach. At the top of the maintenance spectrum is reliability-centered maintenance, which furnishes a comprehensive view of the maintenance infrastructure. The transition to more proactive maintenance strategies will result in fewer equipment failures and an increase in equipment readiness.

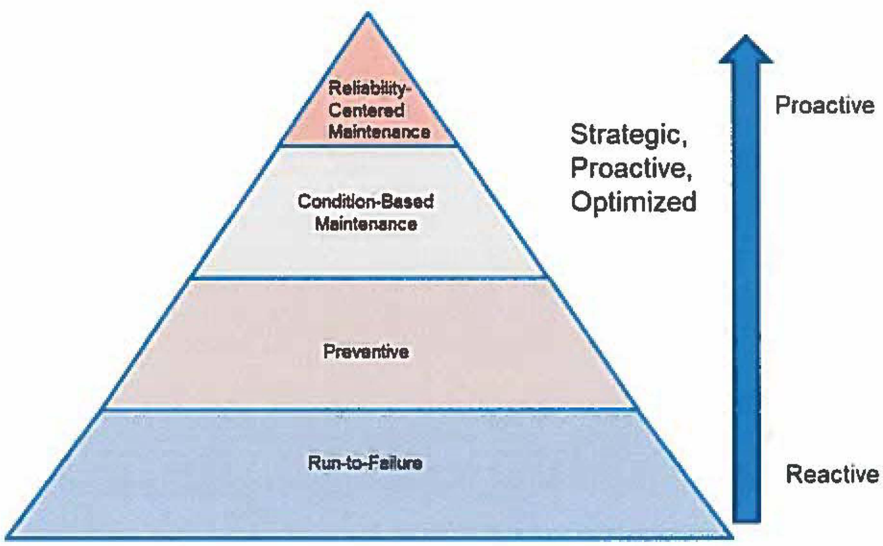
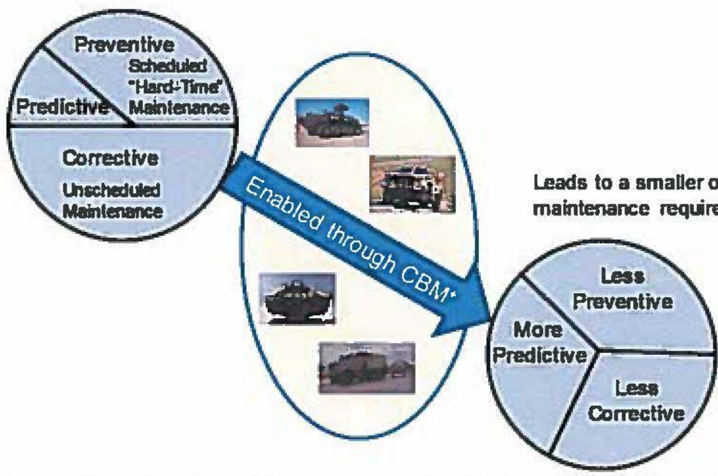



**Figure 2.--Maintenance Strategies**

## *Types of Maintenance Strategies*

Marine Corps Order (MCO) 4790.2, *Field-Level Maintenance Management Policy*, mandates that maintenance will be performed at the lowest unit level possible, consistent with the mission, nature of the repair, authorized repair parts, tactical situation, time available, personnel, skill set, logistical lift, stock positioning of inventory and spares, and authorized tooling.

Maintenance is actions taken to restore or retain materiel in serviceable or operational condition. Maintenance tasks are grouped into two types, preventive (also called preventive maintenance checks and services) and corrective. Preventive maintenance maintains equipment on a regular schedule based on elapsed time or counter reading. Corrective maintenance restores materiel to a serviceable condition. While preventive and corrective maintenance will remain, guidance to the Marine Corps mandates that USMC make strategic investments in data science and technologies to move from corrective (reactive) to proactive (fix at the right time) maintenance by incorporating CBM+ technologies and practices (see Figure 3).




Source: *Condition Based Maintenance Plus DoD Guidebook*, May 2008.

**Figure 3.--Maintenance Evolution**

## *Difference from Today's Maintenance Approach*

Figure 4 illustrates the Marine Corps' efforts to focus on predicting rather than waiting for failure. Many types of equipment 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 can discover the deterioration between the time it is first detectable and the time when functional failure occurs (point "F"), then there is an opportunity to avoid the failure. The time interval from when "P" can be detected and "F" occurs is called the P-F interval. The P-F interval governs how often a CBM task is performed and when action must be taken to correct the impending failure.

By employing CBM+ capabilities, operators and maintainers are aware of pending failures in advance, so they can take appropriate actions to prevent downtime and cost related to experiencing equipment failure. It is this predictive aspect of CBM+ that distinguishes this strategy from traditional approaches to maintenance in the Marine Corps.

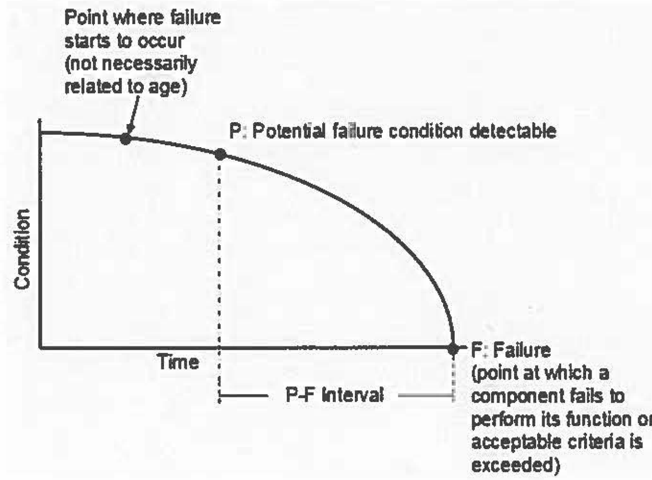



**Figure 4.--P-F Interval**

# Chapter 2

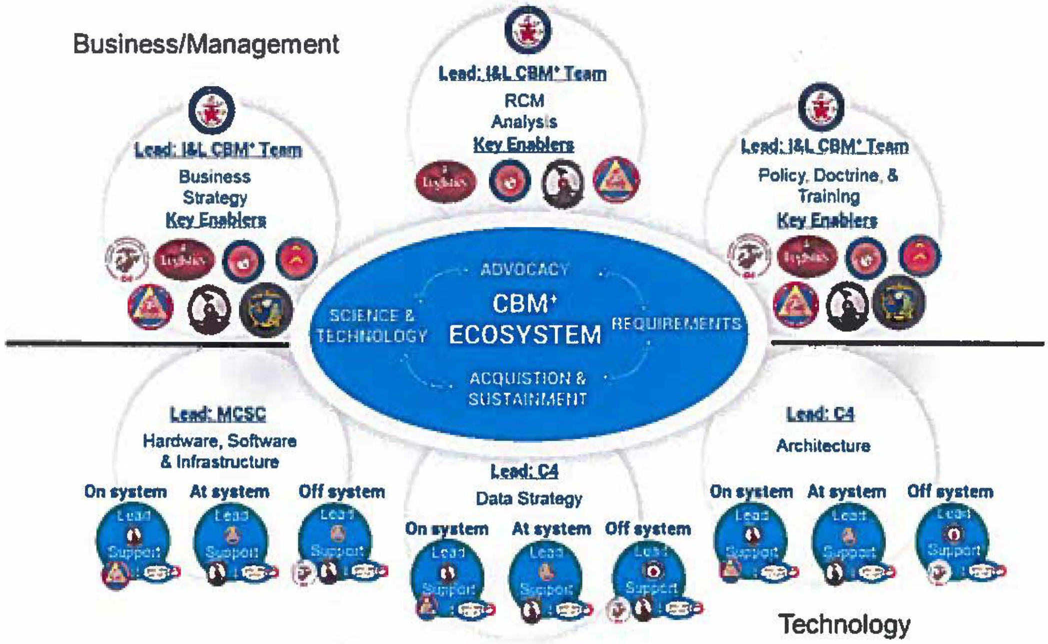
# Condition-Based Maintenance Plus

## *Definition of Condition-Based Maintenance*

CBM is a maintenance strategy that monitors the actual condition of an asset to decide what maintenance needs to be done. The condition of the asset is checked through visual inspections, tests, or analyzing performance data that is gathered by different sensors or tools. CBM dictates that maintenance should be performed only when the data gathered indicates signs of decreasing performance or upcoming failure.

## *The Plus in CBM$^+$*

The "plus" in the CBM$^+$ strategy is the totality of the ecosystem that enables the health assessment of the component or equipment. This health assessment ultimately leads to maintenance actions based on evidence of need (maintenance is based on a forecast of remaining equipment life). This ecosystem (see Figure 5) includes the infrastructure (hardware and software) that is required to make use of sensor-based maintenance information. This infrastructure consists of numerous technologies and enablers. Some of the most prominent enabling tools include automated information technologies (AITs) that facilitate maintenance data collection. In addition to the hardware and enabling tools, a key component of this ecosystem is the network to transmit equipment health data off the platform. The "plus" in the CBM$^+$ strategy expands condition-based maintenance to include a systems-engineering approach to collect data and enable analysis that informs continuous development of maintenance processes and procedures derived primarily from real-time assessment of the weapon system condition obtained from embedded sensors, external tests, and measurements using portable equipment.




Notes: C4 = Command, Control, Communications and Computers; I&L = Installation and Logistics; MCSC = Marine Corps Systems Command.

Figure 5.--CBM+ Ecosystem

## *The Goal of CBM+*

The goal of condition-based maintenance is to monitor and spot upcoming equipment failure so maintenance can be scheduled proactively when it is needed—and not before. Asset conditions need to trigger maintenance within a long enough time period before failure so work can be finished before the asset fails or performance falls below the optimal level.

## *Benefits of CBM+*

If the goal is achieved, the most significant benefit is increased operational availability and reliability of equipment. Commanders have confidence in a predictive process that lessens the chances of disruption to operations. The reduction in corrective and preventive maintenance results in lower maintenance costs (parts and labor), reduced requirements for spare parts, and more effective use of maintainer time and effort. Successful CBM+ implementation also extends the life of Marine Corps equipment. These are crucial benefits at a time when the cost of maintenance is increasing at an unsustainable rate and the service life of Marine Corps equipment is being stretched far beyond its originally intended life span. Other correlated, less tangible benefits are a trained force (maintainers and operators) with an opportunity to improve business processes and create modern maintenance procedures to enhance capabilities.

# Chapter 3
# Reliability-Centered Maintenance

## *Definition of RCM*

According to DoD Instruction (DoDI) 4151.22, RCM is a logical, structured process used to determine the optimal failure management strategies for any system based on system reliability characteristics and the intended operating context. RCM defines what must be done to a system to achieve the desired levels of safety, reliability, environmental soundness, and operational readiness, at best cost. RCM identifies the concepts and methods needed to select technically appropriate maintenance actions that will prevent failure. RCM also identifies default strategies, such as failure finding tasks, engineering redesigns, and changes to operating procedures. RCM seeks to manage the consequences of failure, not prevent them, and it is to be applied continuously throughout the lifecycle of any system.

## *RCM Foundation*

RCM is the foundational process that analyses, selects, prioritizes, and refines $CBM^+$ tasks and processes throughout equipment production, deployment, sustainment, and operational phases. $CBM^+$ not only complements the RCM foundation, but also expands on RCM by applying a spectrum of procedures and capabilities to improve execution of the maintenance analysis process.

## *Relationship of RCM to $CBM^+$*

At its core, $CBM^+$ is maintenance performed based on evidence of need, integrating RCM analysis with those enabling processes, technologies, and capabilities that enhance the readiness and maintenance effectiveness of Marine Corps systems and components. As one of the key enablers of $CBM^+$ and the lifecycle sustainment of Marine Corps weapons systems, RCM ensures that effective maintenance processes are implemented. RCM supplies a logical decision process for calculating optimum maintenance approaches and establishes the evidence of need for reactive and proactive maintenance tasks. RCM and $CBM^+$ have an interactive relationship—RCM is the defining process for calculating the most effective maintenance strategies and $CBM^+$ is one of the maintenance approaches for execution. From a weapon system or equipment perspective, health management without RCM analysis becomes technology insertion without a justified functionality. Figure 6 shows the interactive relationship between RCM, CBM, and $CBM^+$.

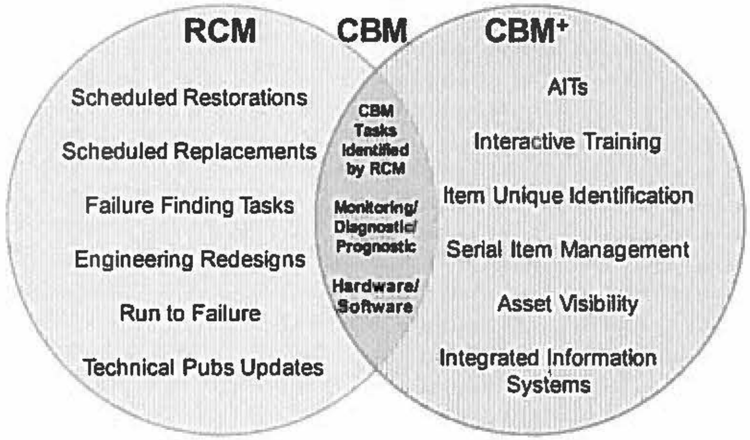



**Figure 6.--RCM-CBM$^+$ Relationship**

RCM improves maintenance tasks and schedules over time as maintainers find the root cause of failures and increase their knowledge of system performance through analysis of equipment usage and maintenance data. The results are a CBM$^+$-enabled maintenance capability that increases reliability, availability, and maintainability of equipment. Successful implementation of RCM leads to an increase in cost effectiveness and reliability, reduced vehicle downtime, and a greater understanding of the level of risk that the organization is managing.

# Chapter 4
# DoD and Marine Corps Policies

The CBM$^+$ strategy was promulgated as DoD policy in a memorandum signed by the Deputy Under Secretary of Defense (Logistics and Materiel Readiness) in November of 2002. This memorandum directs that CBM$^+$ be "implemented to improve maintenance agility and responsiveness, increase operational availability, and reduce life cycle total ownership costs." The policy requires the services to "pursue the examination, evaluation, development, and implementation of CBM$^+$–enabling technologies and process improvements." Since then, DoD policy and numerous Marine Corps policies, as described in this chapter, have been put in place to ensure Marine Corps compliance with CBM$^+$ implementation.

CBM$^+$ applies across many diverse Marine Corps organizations, interests, and policy domains. CBM$^+$ is influenced by decisions made regarding the allocation of resources in many areas impacting CBM$^+$ hardware, software, and communication infrastructure, as well as analytic and decision processes. A consolidated approach to CBM$^+$ governance is needed to drive stakeholder coordination across the Marine Corps. The Marine Corps' governance body will consist of an integrated coordination network among enterprise stakeholders under a tiered governance structure to establish prioritized goals and objectives for effective CBM$^+$ implementation. The governance body will synchronize actions and supply centralized oversight of planning and execution processes to review, measure, and report on CBM$^+$ plans and programs to ensure that CBM$^+$ decisions are made with a comprehensive understanding of costs, benefits, and associated risks. The governance body will inform decision processes on supportability-related requirements; expected support metrics and outcomes; and operating and support cost data, estimates, and assessments. Effective metrics management by the governance body will establish a well-defined baseline for program execution, milestone tracking, and continuous improvement. It will furnish coordinated, authoritative positions on CBM$^+$ implementation, development, and integration to the advocate to inform capabilities development, acquisition, sustainment, and resourcing processes and forums.

## *DoD Instruction 4151.22, Condition-Based Maintenance Plus for Materiel Maintenance*

DoDI 4151.22 establishes policy, assigns responsibilities, and furnishes guidance and procedures for the military departments and defense agencies to implement CBM$^+$. DoD policy requires that CBM$^+$ be implemented for maintenance and logistics support of service weapon systems where cost effective. The scope of CBM$^+$ includes maintenance-related processes, procedures, technological capabilities, information systems, and other logistics concepts that apply to legacy systems and new acquisition programs. This policy requires the Marine Corps to incorporate CBM$^+$ in appropriate policy and guidance, taking into consideration key attributes and best practices.

This instruction also requires implementation of RCM and other appropriate reliability and maintainability analyses for the development of maintenance requirements, maintenance plans, and continually updating maintenance requirements and plans across the lifecycle. It requires program managers (PMs) to design, create, demonstrate, deploy, and sustain equipment in accordance with CBM$^+$ policy and guidance to achieve required materiel readiness at best value.

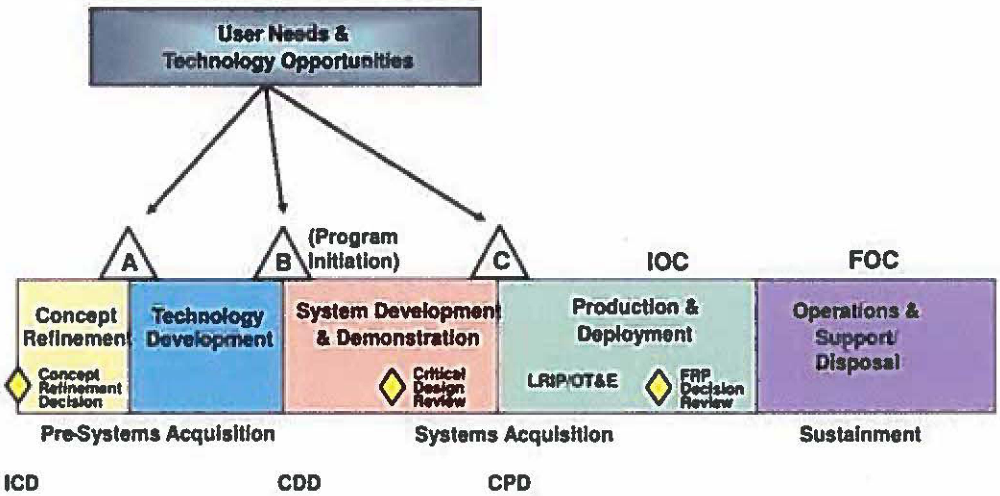
Per DoD policy, CBM$^+$ will

a. be used as a principal consideration in the selection of maintenance concepts, technologies, and processes for all new weapon systems, equipment, and materiel programs based on readiness requirements, lifecycle cost estimate goals, business case analysis (BCA), and RCM-based functional analysis.
b. be implemented into legacy and new weapon systems, equipment, and materiel sustainment programs where technically feasible, beneficial, and cost-effective.

This decision will be based on any of the following: results of RCM analyses, findings from continuous process improvement (CPI) initiatives, technology assessments, and results of supporting BCAs.

### *Marine Corps Order 4000.57A, Marine Corps Total Life Cycle Management (TLCM) of Ground Weapons Systems, Equipment, and Materiel*

Total lifecycle management (TLCM), also referred to as total lifecycle system management (TLCSM), is an approach of managing a system's development from inception to disposal. DoDI 5000.02, *Operation of the Defense Acquisition System*, states that the PM will use a configuration management approach to establish and control product attributes and the technical baseline across the total system lifecycle. Therefore, the PM is the single point of accountability for program objectives for TLCSM. Consequently, the PM implements, manages, and oversees activities associated with the system's development, production, fielding, sustainment, and disposal. Performance-based lifecycle product support is the strategy PMs use in implementing lifecycle management. During acquisition, the PM's focus is on the acquisition community chain (e.g., the Office of the Secretary of Defense [OSD], service secretariat, and program executive officer chain) with requirements input from the user and sustainment communities. Major decisions are based on system-wide analyses with the full understanding of lifecycle consequences on system performance and affordability. Figure 7 shows the 5000 model for TLCSM.




Notes: CDD = Capabilities Development Document, CPD = Capabilities Production Document, FOC = Full Operating Capability, FRP = Full Rate Production, ICD = Initial Capabilities Document, LRIP=– Low-Rate Initial Production, OT&E = Operational Test and Evaluation.

**Figure 7.--TLCSM 5000 Model**

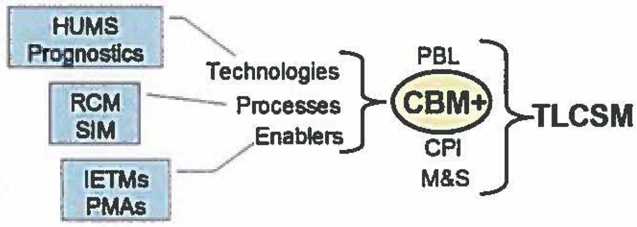
MCO 4000.57A outlines the Marine Corps policy for implementing and managing the TLCM framework for ground weapon systems, equipment, and materiel. TLCM integrates execution responsibilities for all processes encompassing the development production, fielding, sustainment, and disposal of ground weapon systems across their lifecycles. The TLCM framework brings together these interdependent processes to integrate and coordinate actions by process owners better throughout the lifecycle to supply and sustain Marine Air-Ground Task Force (MAGTF) capabilities and readiness. TLCM is the critical enabler for ensuring the highest equipment readiness levels by optimizing materiel solutions across the Marine Corps.

The mission of TLCM policy is to integrate the distinct, but interdependent, processes of the total lifecycle for ground weapon systems, equipment, and materiel, including requirements development, acquisition, fielding, operations, sustainment, and disposal, to maximize asset visibility, availability, supportability, accountability and, ultimately, warfighting capability and readiness.

## *Relationship of CBM$^+$ and RCM to TLCSM*

MCO 4000.57A, *Marine Corps Total Life Cycle Management of Ground Weapon Systems, Equipment, and Materiel*, mandates that sustainment planning is incorporated in documents through the review of established support and sustainment strategies selected during the acquisition process in support of DoD and service-level guidance for such enablers as CBM$^+$ and RCM. MCO 4790.25, *Ground Equipment Maintenance Program* (GEMP), advocates integrating CBM$^+$ concepts and the RCM process into acquisition and sustainment planning and maintenance management decision processes supporting TLCM.

The *Condition-Based Maintenance Plus DoD Guidebook* shows a strong relationship between CBM$^+$, RCM, and TLCSM. CBM$^+$, in concert with the other TLCSM tools (CPI, cause-and-effect predictive modeling and simulation [M&S], and desired outcomes achieved through performance-based logistics [PBL]), will enhance materiel readiness. Figure 8 shows the relationship of these tools to TLCSM.




Notes: HUMS = Health and Usage Monitoring Systems, IETMs = Interactive Electronic Technical Manuals, PMA = Portable Maintenance Aid, SIM = Serial Item Management.

**Figure 8.--TLCSM Relationship with CBM⁺**

Once implemented, CBM⁺ will be the primary reliability driver in the TLCSM supportability strategy. In concert with the other TLCSM enablers, the CBM⁺ strategy will help optimize key performance measures of materiel readiness. 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 lifecycle management processes (such as acquisition, distribution, supply chain management, and system engineering).

To meet the challenges of implementing CBM⁺, management is paying specific attention to CBM⁺ to ensure its timely implementation in new acquisition programs and across the sustainment lifecycle for DoD weapon systems and equipment.

The TLCSM concept ensures the elements of CBM⁺ are fully considered as early as possible in the acquisition lifecycle of a weapon system or equipment. CBM⁺ is an element of TLCSM, emphasizing an early focus on sustainment in the system lifecycle, 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 lifecycle.

It is policy that, as one of the key enablers of CBM⁺ and the lifecycle sustainment of weapon systems, RCM ensures effective maintenance processes are implemented. RCM is a logical decision process for calculating optimum failure management strategies, including maintenance approaches, and establishing the evidence of need for reactive and proactive maintenance tasks.

### *Marine Corps Order 4790.25, Ground Equipment Maintenance Program*

The GEMP defines the performance requirements for ground equipment required to meet DoD and Marine Corps readiness, logistics, and sustainability objectives that enable the Marine Corps to maintain operational capabilities. As these performance requirements increase to keep pace with evolving defense strategies and operational concepts of employment, the Marine Corps must improve ground equipment acquisition, sustainment, and maintenance practices continuously to sustain these capabilities.

The roles and responsibilities outlined in the GEMP supply an integrated framework for a total productive maintenance (TPM) strategy that supports CPI across the full range of actions required to maintain and sustain ground equipment, from initial requirements determination to final asset disposition. The Marine Corps' TPM strategy supports effective TLCM. The GEMP mandates the integration of $CBM^+$ concepts and the RCM process into acquisition and sustainment planning and maintenance management decision processes supporting TLCM. The commander's intent is to leverage people, processes, and technologies to improve TLCM by integrating $CBM^+$ and RCM into the Marine Corps maintenance program. The Marine Corps maintenance strategy will be enabled by enhanced data collection and information management practices and technologies, supplying maintenance managers, PMs, and operational planners with the information required to support effective materiel management decision-making. Implementation of a systemic and integrated GEMP ensures maximum materiel reliability, availability, and maintainability through RCM analyses and $CBM^+$ concepts in the integrated TLCM framework to increase materiel availability.

### *Relationship of $CBM^+$ to the GEMP*

The GEMP defines $CBM^+$ as the application and integration of processes, technologies, and knowledge-based capabilities to achieve target availability, reliability, and operation and support costs of Marine Corps systems and components across their lifecycle. The goals of $CBM^+$ are to perform maintenance only upon evidence of need through RCM, increase equipment availability by uncovering the optimum opportunity to perform required maintenance, and optimize use of resources in conducting maintenance. This shifts equipment maintenance from an unscheduled, reactive approach to a proactive and prognostic approach. To be most effective, $CBM^+$ requires processes, technology, and capabilities that support RCM and maintenance decision-making. These requirements may include automated information systems (AISs) for maintenance data collection and process analysis; sensors embedded in equipment platforms to supply operators, crew, and maintainers with enhanced visibility of equipment condition; or portable equipment for external tests and measurements to support RCM analysis. Accordingly, the Marine Corps will acquire or develop AIT and other test, measurement, and diagnostic equipment, and integrate it with existing and emerging AIS to automate and enhance data collection and sharing to support $CBM^+$.

### *Marine Corps Order 4151.22, Condition-Based Maintenance Plus Order*

The mission of MCO 4151.22 is to implement $CBM^+$, integrating predictive maintenance capabilities to increase operational availability and decrease lifecycle costs, while enhancing lethality and supporting the MAGTF mission. The commander's intent is to implement and integrate $CBM^+$ concepts throughout the total lifecycle framework for the total force. This MCO leverages people, processes, and technologies to integrate $CBM^+$ and RCM in the Marine Corps maintenance program to increase operational availability and support to the warfighter.

This Order applies to ground, aviation ground support, and facilities support organizations. It encompasses DoD-compliant principles and procedures for the implementation and management of $CBM^+$ by doing the following:

1. Implementing $CBM^+$ per the $CBM^+$ definition outlined in DoDI 4151.22 and the guidance in this Order.
2. Using $CBM^+$ as a principal consideration in the research and development of new maintenance concepts, enabling technologies, and processes for all new weapon systems, equipment, and materiel programs based on operational availability, lifecycle cost goals, and RCM-based functional analyses formulated in a comprehensive reliability and maintainability engineering program.
3. Including $CBM^+$ requirements in the development of mandatory sustainment key performance parameters (KPPs) and supporting key system attributes (KSA) for Acquisition Category I (ACAT I) programs.
4. Including $CBM^+$ requirements in the development of sustainment KPPs, KSAs, or sponsor-defined sustainment metrics for ACAT II and below programs.
5. Prioritizing resources for the implementation of $CBM^+$, including product development, procurement, and sustainment.
6. Integrating $CBM^+$ technologies in current weapon systems, equipment, and materiel sustainment programs where it is technically feasible, improves materiel availability, and is cost-effective.
7. Incorporating $CBM^+$ language and requirements into maintenance concepts and contracts for systems and programs supported in organic or commercial sectors.
8. Measuring for success using materiel availability and operational availability as metrics of the sustainment KPP, and reliability and operational cost as the supporting KSAs.
9. Including $CBM^+$ language in the requirements development process which will establish a mechanism for development documents to drive acquisition actions.
10. Ensuring that the provisions of this Order are affected in the administration of the Marine Corps maintenance and maintenance management programs.

# Chapter 5
# Fundamental Elements of CBM+

Implementation of CBM+ requires an enterprise management approach to enable leaders to manage the entire enterprise, rather than individual issues, and synchronize policy and governance, procedures, operations, architecture, and automation requirements. Tools, such as artificial intelligence, an integrated data environment, integrated operations, and metrics-based management, enable enterprise management. Figure 9 depicts the enterprise interrelationships of CBM+.

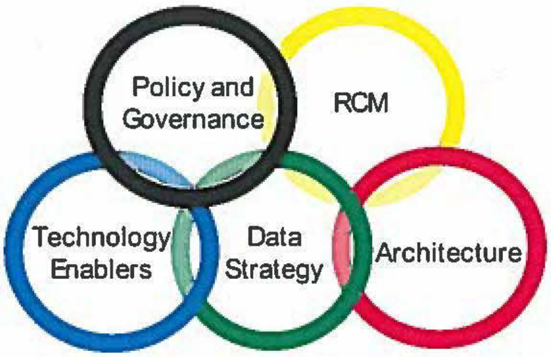



**Figure 9.--CBM+ Enterprise Management Approach**

The enterprise management approach affects many initiatives and programs carried out by Marine Corps organizations. This management approach for CBM+ is designed to engage key players in information collection and analysis and to build consensus for the path forward to the maximum extent possible.

The tenets of CBM+ include the following:

1. **Vision**—Establishes CBM+ as the department's key strategy for sustaining weapon system readiness at best cost.
2. **Strategy, Policy, and Planning**—Clear and strong guidance, including policy, strategy, action plans, and road maps at all levels, underlies the successful planning, implementation, and sustainment of CBM+ execution.
3. **Organization**—CBM+ execution requires a holistic and systematic approach spanning multiple organizations, functional disciplines, and communities.
4. **Resources**—Sufficient personnel and funding are essential for development, planning, implementation, and sustainment of any systemic effort.
5. **Technologies and Tools**—Appropriate tools and technologies are necessary to execute CBM+ successfully.
6. **Workforce**—A workforce trained on basic CBM+ principles is essential.

The initial acquisition phase of a weapon system is the most opportune time to consider and implement capabilities that improve readiness, optimize maintainer resources, and reduce operation and support cost over the lifecycle. Legacy weapon systems that were developed and fielded without $CBM^+$ consideration must 1) establish governance structures that include all relevant stakeholders; 2) create action plans and milestones that support the military services' established policies, strategies, and vision of $CBM^+$; and 3) pursue $CBM^+$ through the examination, evaluation, and implementation of enabling technologies, tools, and process improvements.

### *Policy and Governance*

Policy exists today for the implementation of $CBM^+$ in DoD and the Marine Corps. DoD policy was issued to the services October 16, 2012, with an updated version expected in early 2020. To comply with DoD policy, Marine Corps policy for $CBM^+$ guides the enterprise-wide integration efforts and further defines the respective roles and responsibilities for key stakeholders. 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.

### *RCM as the Foundation*

The decision to employ $CBM^+$ on a weapon system starts with understanding the application of RCM as the foundational process that analyzes, selects, prioritizes, and refines CBM tasks. CBM tasks derived from the RCM method to monitor operating equipment to uncover impending failure are called condition-monitoring tasks. When these tasks are automated, using sensors in and on the platform to detect the signals of an impending out-of-tolerance condition that will lead to failure, the result is an example of CBM. When this process is aided by technology, it is called $CBM^+$. Through $CBM^+$, data is collected from the weapon system, end item, component, etc. and diagnostic algorithms (based on fleet operating history and environmental factors) are applied to assess the status and prompt the maintenance process to start proactive intervention to halt the effect of a failure cycle.

### *Technology Enablers*

Numerous technologies and enablers are required to use sensor-based maintenance information. OSD has included several enablers under its $CBM^+$ initiative:

- Prognostics
- Diagnostics
- Portable Maintenance Aids (PMAs)
- Interactive Electronic Technical Manuals (IETMs)
- Interactive Training
- Data Analysis
- Integrated Information Systems
- Automatic Identification Technology.

Enablers, such as PMAs and IETMs, facilitate continuous measurements from sensors installed on platform or periodic measures at platform. This collection of data enables maintainers to measure the operating condition of equipment. With other technology, such as equipment health and usage management systems installed on multiple platforms, maintainers monitor the health of the platform. Through this type of monitoring, maintainers find and analyze defects (diagnostic), project an estimated future condition (predictive), and calculate the remaining useful life (prognostics). Ultimately, this technology shifts maintenance from an unscheduled, reactive approach to a predictive one (by analyzing data collected automatically through sensors and forecasting when maintenance is needed).

### *Data Strategy*

CBM$^+$ relies on the movement of platform data to various places in the enterprise. This movement requires a supporting communications and information systems infrastructure. Key elements of the infrastructure must include server functionality at the unit to support movement of CBM$^+$ data from the platform to other users. These capabilities supply publish-and-subscribe services and manage file transfers and related movement of data up and down the system. Data can be collected from the system by two methods: (1) spot readings at regular intervals using portable instruments or (2) sensors retrofitted to equipment or installed during manufacture for continuous data collection. Data is crucial—it can be turned into information that enables operators and maintainers to make better maintenance decisions. The ability to store and analyze this data is vital to the overall goal of CBM$^+$. It's the analysis of trends that supports changes to policies and procedures to improve overall maintenance processes. Figure 10 describes the continuous data feedback loop designed to achieve this goal.

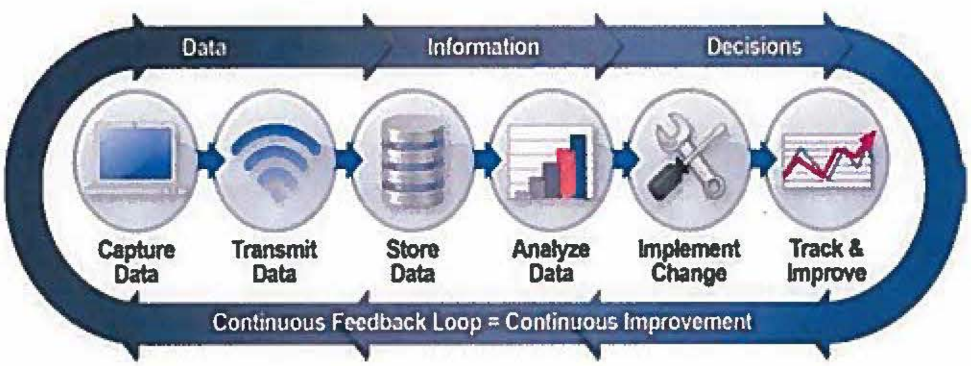



**Figure 10.--Continuous Data Feedback Loop**

From an open, non-proprietary data strategy viewpoint, an overriding concern is to ensure that all CBM$^+$ systems, including the CBM$^+$ data warehouse, conform to the open architecture data standard formats published by the Machinery Information Management Open Systems Alliance (MIMOSA). This specification mirrors the data flow hierarchy in International Organization for Standardization 13374-1, the international standard that MIMOSA implements for condition monitoring and other CBM$^+$ applications. These specifications can be applied as the basis for a supporting data strategy for a common CBM$^+$ operating environment. From a data management viewpoint, it is desirable that CBM$^+$ data exchanges and storage conform to the open systems architecture for enterprise application integration, the data flow hierarchy that is based on the open architecture standard published by MIMOSA.

## *Architecture*

An architecture is the structure of components, their relationships, and the principles and guidelines governing their design and evolution over time. The DoD Architectural Framework (DoDAF) defines a common approach for architecture description development, presentation, and integration for DoD's warfighting operations and for business operations and processes. The framework ensures design descriptions and interfaces can be compared and related throughout the product or process lifecycle across organizational and functional boundaries. The logistics chain integrated architecture is one of the Marine Corps' DoDAF-compliant logistics architecture. However, this architecture does not reflect $CBM^+$ business processes. The simplest way to understand an architecture designed to support $CBM^+$ is to use the analogy of building a house (see Figure 11). From an operational viewpoint (OV), if the task is to prepare food, the operational need is a kitchen. From a systems and services viewpoint, if the functions are to store, wash, and cook food, the required systems are a refrigerator, a sink, and a stove. From a standards viewpoint, the specifications are pipes, currents, and voltages and the appropriate standards are 220 VAC, 120 watt, etc. The $CBM^+$ architecture functions in the same manner. There are multiple parts that all must interface (i.e., platform hardware and software, digital interface between health management computers and sensors, a command and control [C2] system and compatible IT infrastructure).

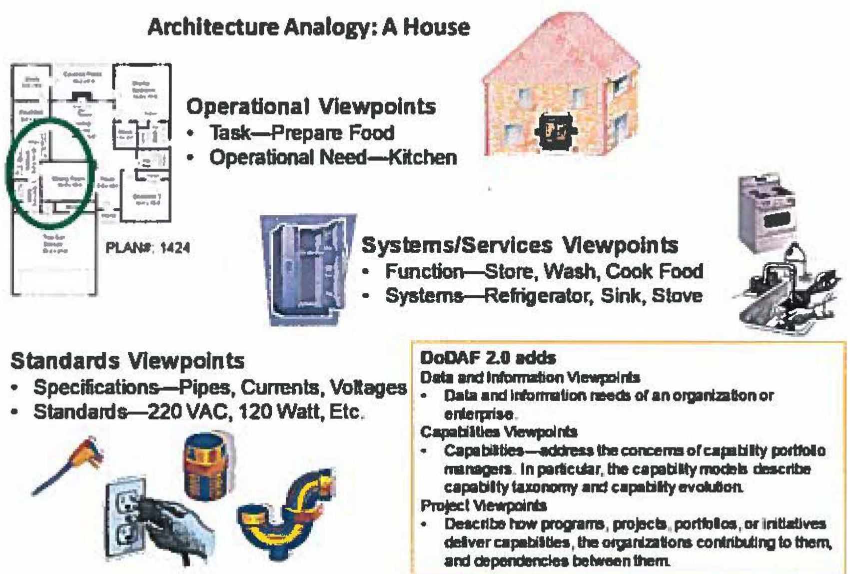



**Figure 11.--Architecture Analogy**

By DoD mandate and good engineering practice, the DoDAF construct is based on industry open-architecture specifications and widely accepted data models. $CBM^+$ implementers in the Marine Corps must make use of the DoDAF conventions to describe the full scope of the $CBM^+$ initiative effectively.

# Chapter 6
# Systematic and Incremental Implementation of CBM⁺

## *On-System Components*

In a CBM environment, operating platforms, embedded sensors, inspections, and other events trigger when restorative maintenance tasks are required based on evidence of need (see Figure 12). Embedded software on platforms and major components assesses the condition of the equipment using information from built-in test equipment, sensors, and other usage data. This information is shared with C2 systems to enable automated status feeds to the tactical and logistics situational awareness systems. Information shared with the platform C2 system is generally exceptional or report data and does not include all available CBM⁺ data.

Software on the system interprets sensor readings and other operating parameters to indicate existing or potential malfunctions. Operating and maintenance data is captured and stored for future analysis off platform.

CBM as a maintenance strategy is typically applied to high-value failures—which are not necessarily the same as high-value components. High-value failures have the greatest effect on the metric of choice—cost of operation, mission performance, operational availability, or some other value basis. It is also possible to use manual inspection techniques (e.g., visual inspections or functional tests) to perform classic CBM tasks. The decision to automate a CBM maintenance task by installing platform sensors should be based on a cost-benefit analysis as part of equipment design.

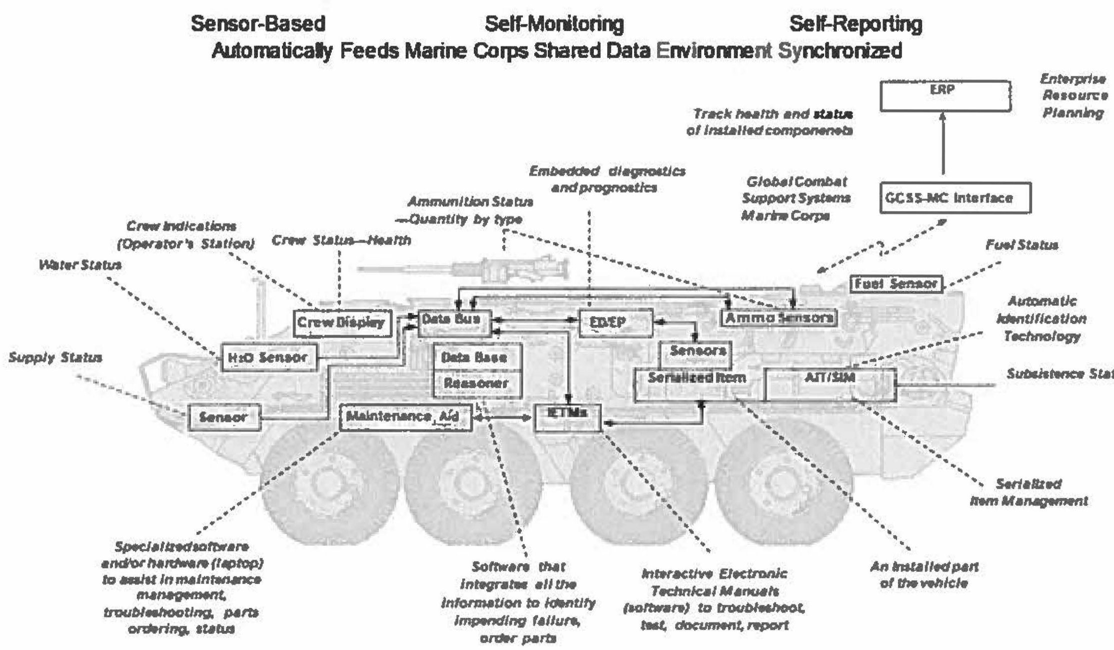



**Figure 12.--On-System Integrated Weapon System Status Sensors**

The remainder of this chapter details the "plus" of CBM⁺.

### *At-System Components*

Maintenance aids support operator- and maintainer-level maintenance tasks. Aids for maintainers furnish capabilities to perform tests and analyses not available from on-board systems. The Electronic Maintenance Support System (EMSS) is a key Marine Corps maintenance aid designed to enhance combat service support to MAGTFs while deployed or in garrison. EMSS consists of an electronic maintenance device and accessories.

Maintenance aids include both on-system software and portable computers and software used at system. The at-system portable computer used by maintainers is called a PMA in $CBM^+$ policy documents. The PMA hosts the software used by maintainers to carry out at-system maintenance tasks, such as condition monitoring, diagnostics, prognostic analysis of platform data, and fault isolation and repair. PMAs augment on-board systems, although they typically do not operate in real time. They support condition-based and corrective maintenance tasks. The suite of maintenance aids could include portable computers, portable test equipment, and software.

### *Off-System Components*

Data pulled from platforms and equipment is used at the field level to schedule maintenance and manage readiness. The data is also passed over the communications and information infrastructure to a national-level data warehouse. Lifecycle managers, original equipment manufacturers, and others use analysis and decision support tools to mine the data to discover adverse trends, improve diagnostic routines, find targets for product improvement programs, refine maintenance plans, establish budgets and inventory levels for repair parts, issue maintenance bulletins, and plan and budget rebuild and reset programs.

### *Network*

$CBM^+$ relies on the movement of system data to various places in the enterprise. This movement requires a supporting communications and information systems infrastructure. Reliable local area network (LAN) and wide area network (WAN) coverage supplies the basic network backbone needed to support movement of $CBM^+$ data and automation of other maintenance and logistics tasks. Network administrators install, operate, and maintain LANs and WANs to enable command and control.

The Marine Corps Enterprise Network (MCEN) is the Marine Corps' network of networks and approved interconnected network segments. The MCEN interfaces with external networks to furnish information and resource sharing as well as access to external services. The MCEN supplies robust, seamless, and secure end-to-end communications—from the supporting establishment to the Marine Corps forward deployed forces.

An overview of the $CBM^+$ architecture is shown in Figure 13.

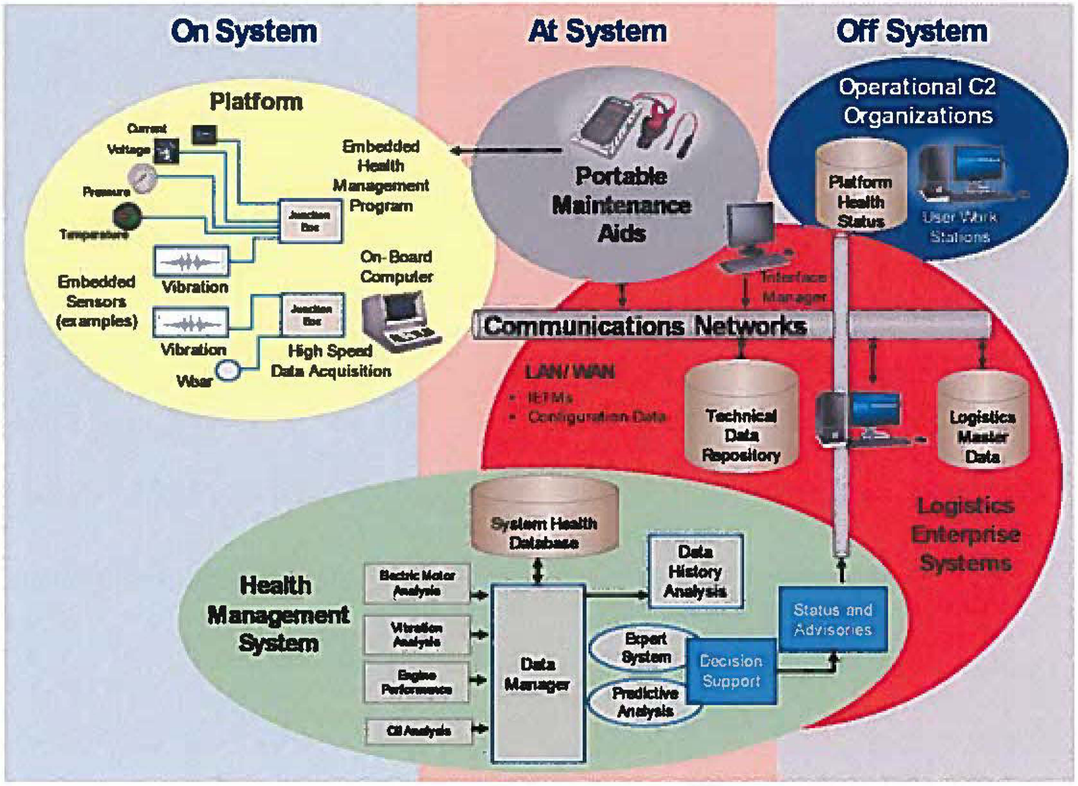



**Figure 13.--CBM⁺ OV-1 Architecture Overview**

# Chapter 7
# Measuring Success

**Pilots.** The Marine Corps is conducting a series of pilots to test $CBM^+$ maintenance concepts, enabling technologies, and processes. These pilots show enhanced operational readiness, cost benefits, and improved operational availability. The Marine Corps is also testing $CBM^+$ concepts at installations to create opportunities for maintenance and energy savings as well as an enhanced installation operational picture.

**Metrics.** The Marine Corps has selected metrics in support of measurable OSD objectives of a maintenance program to assess whether $CBM^+$ initiatives are enabling a more effective maintenance process. Materiel availability, materiel reliability, ownership cost, and mean down time (MDT) will initially help track the effects of $CBM^+$ implementation. The amount of time and funding resources required makes this analysis an integral part of the $CBM^+$ effort. As with any initiative, effective metrics management establishes a well-defined baseline for program execution, milestone tracking, resultant outcomes, and continuous improvement. Measures of performance and effectiveness enable effective implementation and execution and furnish a basis for investment in $CBM^+$ enablers and processes.

Under the TLCSM concept, four metrics areas have been established as lifecycle sustainment outcome metrics appropriate to use when evaluating $CBM^+$ implementation. The metrics are defined as follows:

- Materiel availability is a measure of the percent 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. Materiel availability also indicates the percent of time a system is operationally capable of performing an assigned mission and can be expressed as uptime divided by the sum of uptime and downtime.
- Materiel reliability is a measure of the probability the system will perform without failure over a specific interval. Reliability must be sufficient to support the warfighting capability needed. Materiel reliability is generally expressed in terms of a mean time between failures, and, once operational, can be measured by dividing actual operating hours by the number of failures experienced during a specific interval.
- Ownership cost balances the sustainment solution by ensuring the operating and support (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.
- MDT is the average total time required to restore an asset to its full operational capabilities. MDT includes the time from reporting an asset being down to the asset being given back to operations or production to operate.

To date, the Marine Corps has defined the metrics found in Table 1 to measure success during CBM⁺ implementation.

| Metric Area | Metric | Metric Definition | Measure |
|---|---|---|---|
| **Availability** | Materiel Availability | A measure of the percent of the total inventory of a system operationally capable (ready for tasking) of performing an assigned mission at a given time, based on materiel condition. | Number of Available Primary End Items (PEIs) ÷ Total Population of PEIs |
| | Operational Availability | The measure of the percent of time that a system or group of systems in a unit are operationally capable of performing an assigned mission. | Uptime ÷ (Uptime + Downtime) |
| | Mission Availability | The measure of the percent of time that all mission-critical subsystems on a CBM⁺-enabled PEI are operationally capable of performing all assigned mission or training tasks for a contingency operation or training event. | Mission Available Time ÷ Mission Event Time Training Available Time ÷ Training Event Time |
| **Reliability** | Materiel Reliability | A measure of the probability that the system will perform without failure over a specific interval. | Operating Miles ÷ Number of Failures<br>Operating Time ÷ Number of Failures |
| | Mission Reliability | The measure of the ability of an item to perform its required function for the duration of a specified mission profile. | Random Failure-Free Mission Events ÷ All Mission Events Random Failure-Free Training Events ÷ All Training Events |
| **Ownership Cost** | CBM⁺ Product Improvement Cost | Total cost of improvements to CBM⁺ technology required to achieve CBM⁺ goals and objectives for a maintainable PEI. | CBM⁺ Development Cost ÷ PEI Program |
| | Cost of Unscheduled Downtime | The total cost of an equipment mission failure for maintenance costs of the repair, lost training time, and lost mission time. | Total Cost of Failure ÷ PEI Program |
| **Maintainability** | Mean Down Time | The average total downtime required to restore an asset to its full operational capabilities. | Sum of Downtime ÷ Sum of Maintenance Events |
| | Mean Unscheduled Mission Down Time | The average total unscheduled down time during a mission or training event (MTE), required to restore an asset to its full operational capabilities when a random failure occurs due to monitored mission-critical component. | Sum of Unscheduled MTE Downtime ÷ Sum of Unscheduled MTE Maintenance Events |
| | Mean Unscheduled Down Time | The average total unscheduled down time, at any time, required to restore an asset to its full operational capabilities. | Sum of Unscheduled Downtime ÷ Sum of Unscheduled Maintenance Events |

**Table 1.--Marine Corps Metrics**

The Marine Corps will establish metrics in system acquisition planning documents (e.g., Joint Capabilities Integration and Development System Initial Capability Document) as well as metrics at the Marine Corps level to assess overall CBM⁺ capability progress. Appropriate goals and metrics are the key to evaluating the effectiveness of an investment.

# Conclusion

Basing maintenance activities on actual conditions rather than on a predetermined schedule can mature maintenance work to a new level of efficiency. Fewer preventable damages and failures result in improved equipment availability and more efficient operation for longer periods of time. Faster and more confident maintenance decisions and a significant reduction in work orders are motivating factors for the maintenance crew. With advance warning of system failures, unexpected breakdowns can be substituted with planned repairs, enabling more time spent uncovering areas for further improvement of machine performance, energy efficiency, or output.

APPENDIX A

Glossary of Terms and Abbreviations

Acronyms

| | |
|---|---|
| ACAT | Acquisition Category |
| AIS | Automated Information System |
| AIT | Automated Identification Technology |
| ASN(RDA) | Assistant Secretary of the Navy (Research, Development, and Acquisition) |
| BCA | Business Case Analysis |
| C2 | Command and Control |
| CBM | Condition-Based Maintenance |
| CBM+ | Condition-Based Maintenance Plus |
| CDD | Capability Development Document |
| CPD | Capability Production Document |
| CPI | Continuous Process Improvement |
| DASN-S | Deputy Assistant Secretary Navy - Sustainment |
| DoD | Department of Defense |
| DoDAF | DoD Architecture Framework |
| DoDI | DoD Instruction |
| DON | Department of Navy |
| DOTMLPF | Doctrine, Organization, Training, Materiel, Leadership, Personnel, Facilities |
| FOC | Full Operating Capability |
| FRP | Full Rate Production |
| EMSS | Electronic Maintenance Support System |
| GEMP | Ground Equipment Maintenance Program |
| HUMS | Health and Usage Monitoring Systems |
| ICD | Initial Capabilities Document |
| IETM | Interactive Electronic Technical Manual |
| JCIDS | Joint Capability Integrated Development System |
| JLEnt | Joint Logistics Enterprise |
| KPP | Key Performance Parameter |
| KSA | Key System Attribute |
| LAN | Local Area Network |
| LRIP | Low-Rate Initial Production |
| MAGTF | Marine Air-Ground Task Force |
| MCEN | Marine Corps Enterprise Network |
| MCO | Marine Corps Order |
| MCI3B | Marine Corps Installations and Infrastructure Investment Board |
| MDT | Mean Down Time |
| MIMOSA | Machinery Information Management Open Systems Alliance |
| M&S | Modeling and Simulation |
| MTE | Mission or Training Event |
| O&S | Operating and Support |
| OSD | Office of the Secretary of Defense |
| OT&E | Operational Test and Evaluation |
| OV | Operational Viewpoint |
| PBL | Performance-Based Logistics |
| PEI | Primary End Item |
| PII | Personal Identifiable Information |
| PM | Program Manager |
| PMA | Portable Maintenance Aid |

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|---|---|
| RCM | Reliability-Centered Maintenance |
| RCMA | Reliability Centered Maintenance Analyst |
| RTF | Run-to-Failure |
| R&M | Reliability and Maintainability |
| SIM | Serial Item Management |
| TLCM | Total Lifecycle Management |
| TLCSM | Total Lifecycle Systems Management |
| TPM | Total Productive Maintenance |
| USMC | United States Marine Corps |
| WAN | Wide Area Network |

## Definitions

Condition-Based Maintenance (CBM). CBM is 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. CBM 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 CBM is to perform maintenance based on the evidence of need while ensuring safety, reliability, availability, and reduced life-cycle cost.

Condition-Based Maintenance Plus (CBM+). CBM+ is 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+ leverages reliability centered maintenance principles 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.

Reliability-Centered Maintenance (RCM). RCM is 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.

Evidence of need. The data, research or other form of appropriate evidence collated and used to demonstrate the demand or need for a business, enterprise, specific action, specific change, financial support, government service, organization, community development plan, community action plan, product, project or a service. RCM provides the evidence of need for other CBM+ processes and technologies, such as health monitoring or prognostics. RCM provides an understanding of the applicability and effectiveness of proposed CBM+ technologies as well as an analysis of alternatives.