Assessment of DoD Transition to Condition-Based Maintenance

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INTRODUCTION

This report is the second of two reports on DoD's transition to condition-based maintenance (CBM). In our first report, we looked at the technology of CBM and selected applications.[1] This report examines four CBM programs, focusing on their architectures, goals, metrics, resources, and paybacks.

Many DoD senior managers expect CBM to support the maintenance transformation required by Joint Vision 2010 and Focused Logistics. They further expect that it will help solve the systemic military maintenance dilemma associated with aging weapon systems, less money for maintenance, and fewer trained maintenance technicians. In addition, there is a general perception that CBM is a concept of the future. Although many CBM technologies fall in that category, CBM has been around for more than 30 years, beginning in commercial aviation in the 1960s. Moreover, the infrastructure for CBM has also been evolving in commercial industrial markets for more than 20 years.

In this report, we examine several management issues associated with major CBM development programs. As part of our research, we reviewed a wide range of technical development efforts and studies on the subjects of integrated diagnostics, prognostics, and CBM. Our examination of DoD's CBM development programs uncovered a number of disconnects between expectations for CBM and the reality of development programs. Those disconnects merit discussion and need attention. We hope this report stimulates that discussion, and in so doing, increases the success quotient for CBM in military programs in general.

[1] Logistics Management Institute, *An Assessment of Condition-Based Maintenance in the Department of Defense*, August 2000.

The four CBM programs we examined are listed below:

- *Army Diagnostic Improvement Program (ADIP)*—This program is aimed at improving the diagnostics and prognostics of Army weapon systems and equipment. Its scope includes all ground and air fighting vehicles (such as tanks, trucks, and artillery); missiles; aircraft; as well as combat support and combat service support equipment including engineer equipment, watercraft, communication-electronic equipment, and mobile power generators.

- *Integrated Condition Assessment System (ICAS) and Monitoring Program*—ICAS, a trademarked commercial product, is a data acquisition and analysis system comprised of hardware, software, and sensors for monitoring equipment and scheduling maintenance based on equipment condition. Under this program, the Navy is installing ICAS on approximately 320 surface ships in both the Atlantic and Pacific Fleets.

- *Integrated Mechanical Diagnostics–Health Usage and Monitoring System (IMD–HUMS)*—This system is a Commercial Operations and Support Saving Initiative designed to improve helicopter operational readiness and flight safety while reducing maintenance-related costs. The Navy plans on installing IMD-HUMS on its helicopters, including the H-53E, SH-60/CH-60, and S-92/S-76C/S–76A aircraft. All of these aircraft are Sikorsky helicopters.

- *Joint Strike Fighter Prognostics Health Maintenance (JSF PHM) Program*—PHM is part of a support concept for the JSF. It provides advanced on-board diagnostics and testability that includes on-condition maintenance, system configuration, and autonomic logistics support. (Autonomic logistics refers to the concept of tying logistics information systems together and automatically triggering appropriate logistics responses from CBM inputs.)

In our research of DoD’s CBM programs, we reviewed numerous research and development projects, including Advanced Concept Technology Demonstrations and Broad Agency Announcements. We had extensive dealings with the JSF PHM program and with ADIP. For the past year, we attended selected Technical Interchange Meetings conducted by the JSF Supportability Program Office for PHM. We also participated in selected ADIP integrated product team meetings with sidebars on various diagnostic subjects.

To obtain a better understanding of the Navy’s view of CBM, we met with a variety of key maintenance and resource managers and planners. We also reviewed Navy policy on CBM and NAVSEA’s approach to CBM, which we consider visionary. To obtain a better feel for the legacy ship maintenance environment, we went aboard the USS Frederick for a detailed look at the legacy maintenance issues for hull, mechanical, and electrical equipment.

Additionally, during the past year we examined the CBM issues in the commercial industrial sector and reviewed numerous publications on CBM.

OVERVIEW

Report Objectives

Our examination of the four CBM programs focused on five areas:

- *Architecture*–How well has building a CBM system been thought through? Does it have an up-front maintenance strategy? Is it built upon the principles and standards of an open systems architecture?
- *Program Goals*–What are the goals of the program? Are they broad based (and strategically focused) or narrowly focused? Is there any symmetry between high-level expectations for CBM and the program goals?
- *Program Metrics*–How is success measured? What kind of metrics are being used and how effectively?
- *Resources*–Have adequate resources (funding) been programmed to achieve program goals?
- *Payback*–What kind of payback or benefits have been achieved or are expected? What is the return on investment?

Findings and Conclusions

As a result of our examination, we found or concluded the following:

- Architecture
  - Some CBM programs are not being driven by enterprise-wide maintenance strategies.
  - All programs emphasize, to some degree, the use of open systems architectures.
- Goals
  - The disparity in goals suggests limited coordination among the programs.
  - Not all programs have broad-based goals or have a strategic focus.

- No program explicitly addresses all of DoD's high-level maintenance transformation expectations.
- Most programs have established cost-reduction goals.

- Metrics
  - Some programs have not yet developed any metrics.
  - Most programs need to improve their use of metrics.
- Resources
  - A prevailing short-term funding focus creates inadequate long-term funding and jeopardizes long-term program goals.
  - Two of the programs (ADIP and ICAS) are significantly underfunded.
- Payback
  - Some cost-benefit analyses have been completed; the preliminary results are encouraging, but spotty.
  - Determining the return on investment from CBM programs is difficult because of limited data and the absence of adequate metrics.

Recommendations

To correct or resolve the above issues, we believe DoD needs to take the following actions:

- *Goals*–Establish additional, broader goals for CBM programs. Those goals and should be aligned with the strategic vision of the Joint Chiefs of Staff and with the strategic plans of the Deputy Under Secretary of Defense for Logistics and Materiel Readiness and the Military Services. They should also focus on reducing costs.
- *Metrics*–Establish metrics and benchmarks for all CBM programs and share them throughout DoD.
- *Resources*–Meet the CBM program funding shortfalls expeditiously. If these programs are unable to meet their goals, they will not contribute materially to the Focused Logistics tenets of Joint Vision 2010.
- *Payback*–Share cost-benefit and return on investment factors among all CBM programs so successful approaches can be of value to other programs.

In a closely related issue, one of the tenets of Focused Logistics and Joint Vision 2010 is the sharing of maintenance capabilities and facilities across the Military Services. We believe CBM programs can benefit from a similar sharing of goals, metrics, and payback targets. To ensure that such sharing occurs, we further recommend DoD designate an advocate for CBM.

The DoD advocate should be at a sufficiently high management level to have visibility over all CBM research and development programs. The Assistant Deputy Under Secretary of Defense for Maintenance Policy, Programs and Resources is at the appropriate level and has the charter to fill this role. In that capacity, the ADUSD should undertake several important tasks in the near term.

- Identify and monitor the status of all strategic CBM programs: A strategic CBM program is any program whose failure could jeopardize the implementation of Focused Logistics. Examples of such programs include ADIP, ICAS and JSF PHM. These programs have a time horizon that extend close to or beyond the 2010 timeframe and they have an equipment implementation scope such that if they don't achieve their objectives they will have little time or money left to construct alternative CBM initiatives.

- Support additional resources for some CBM programs: Some CBM programs may warrant additional resources to achieve their goals.

- Establish information exchanges with the Military Services: The advocate should champion the sharing of best technical and management practices across CBM programs. A standing forum (formal or informal) may be an effective way to share that type of information.

CBM Issues

Background

The 'To-Be' state in Joint Vision 2010 and the Focused Logistics Roadmap establish several logistics and maintenance expectations:

- Agile infrastructure, including right-sized logistics footprint; velocity-based maintenance and logistics; and, precision logistics

- Increased responsiveness, visibility, and accessibility of logistics resources

- Intelligent and intuitive decision support

- Proactive to the logistic and maintenance needs of the warfighter

- Shorter overall repair cycle time

- Sharing of maintenance capabilities, and facilities
- Better use of embedded diagnostics and telemaintenance to enhance prognostics.

The DoD Logistics Strategic Plan, 1998 edition, called for initial implementation of the fundamental characteristics of Focused Logistics within 5 years. That plan has spurred the publication of various Military Service documents. As an example, the Army Strategic Logistics Plan calls for these achievements:

- Improved maintenance procedures through electronic and interactive electronic tech manuals
- Embedded diagnostics, sensors, and on-board prognostics
- On-board platform (weapon system) sensors, diagnostics, and prognostics linked directly to information and decision support systems
- Delivery of effective equipment maintenance with fewer resources and older weapon systems.

The combination of these achievements is our starting point for examining CBM development programs. We carried out our examination in the context of the five areas: architecture, goals, metrics, resources, and payback.

Architecture

Well-designed CBM programs combined with autonomic logistics have the potential to reduce false alarm rates, lower inventory requirements, and improve turnaround rates for mission equipment. In our review, we sought to determine what DoD has done to ensure that CBM programs are well designed and not simply technology insertion exercises. We specifically addressed two fundamental questions during our review:

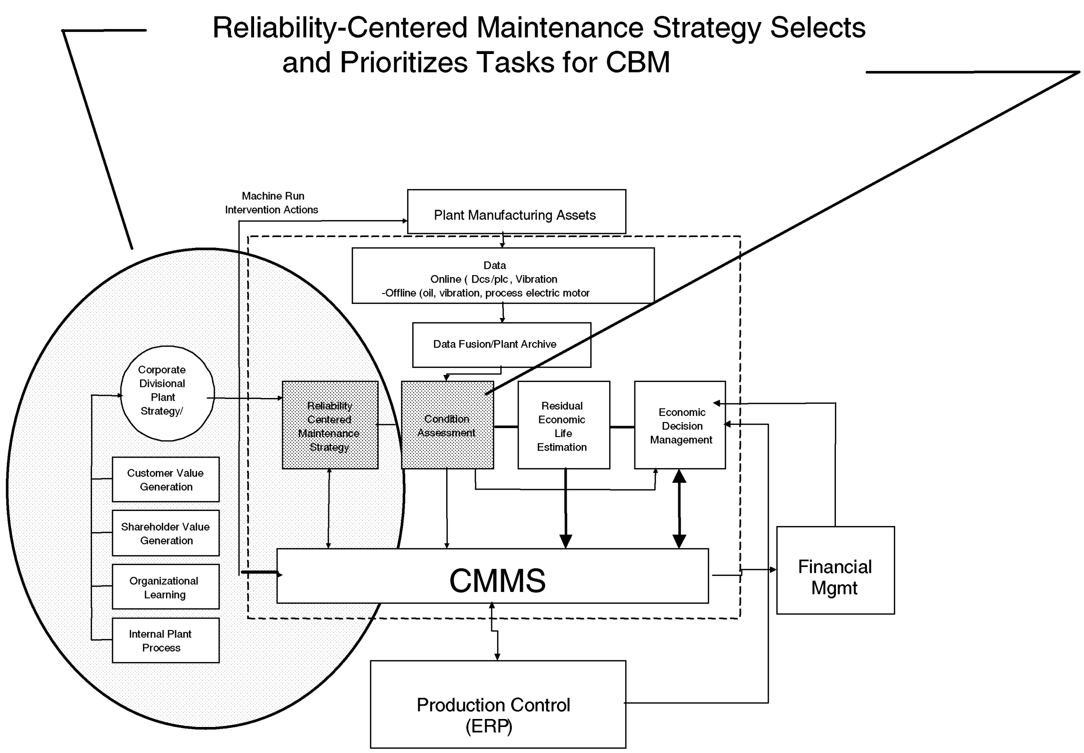
- Is the CBM program part of an overall maintenance strategy that was developed through an up-front equipment maintenance assessment of need?
- Is the CBM program based upon open systems architecture principles and guidelines?

OBSERVATION: CBM NEEDS TO BE PART OF AN OVERALL MAINTENANCE STRATEGY

An up-front analysis of DoD weapon systems, sub-systems, and components with their associated failure modes must precede the development of new maintenance processes. At the enterprise level, this analysis determines the overall maintenance strategy. Historically, this type of analysis has been fundamental to reliability-centered maintenance (RCM). RCM and its derivatives have been formalized into a master set of principles and processes by which an enterprise analyzes its physical assets and determines the optimum maintenance strategy for them, including how and where to implement CBM.

Commercial applications of CBM show that the best results are achieved when implementation is part of an enterprise-wide strategy. The analysis that leads up to CBM involves a bottoms-up assessment of enterprise assets to build an understanding of how the equipment fails and what the consequences are for every type of failure. (In DoD, this assessment is called failure modes and effects criticality analysis and is a meaningful deliverable in equipment contracts.) That assessment also drives the enterprise strategy of maintenance. Figure 1 shows a corporate example of RCM driving CBM processes.[2]

Figure 1. Reliability-Centered Maintenance Strategy Drives CBM Applications



OBSERVATION: THE NAVSEA RCM-CBM APPROACH TO MAINTENANCE STRATEGY IS A VISIONARY EFFORT

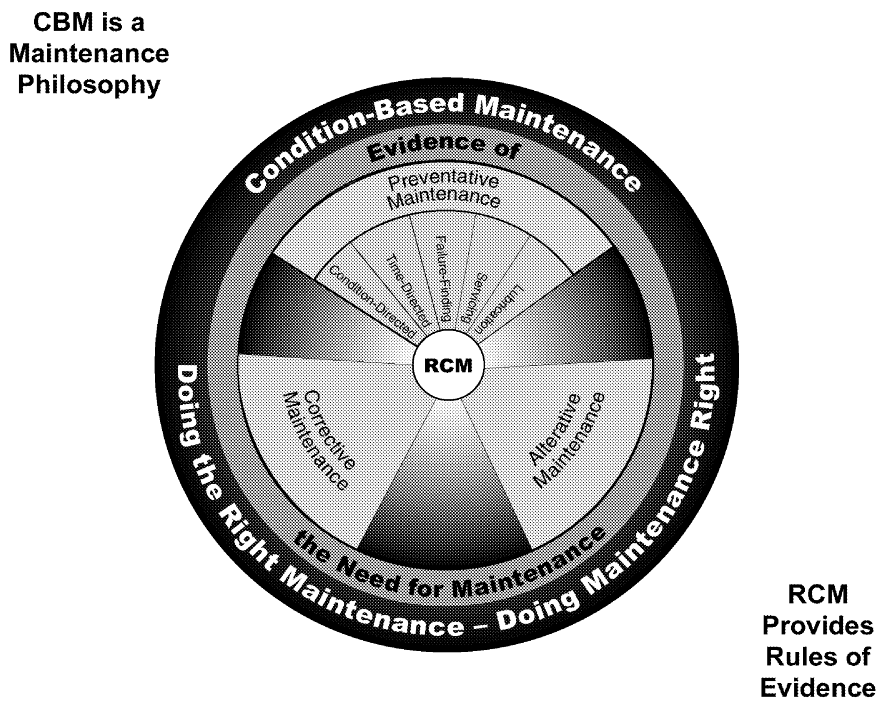
The Chief of Naval Operations has directed NAVSEA to use RCM when evaluating Navy maintenance requirements. In response, NAVSEA is developing an

[2] Martin Dundics, "A Common Denominator for Effective Exchange with CMMS Systems," MIMOSA Meeting in Scottsdale, AZ, 1998.

RCM Certification Program for all engineers and commodity specialists responsible for developing, reviewing, or approving changes to maintenance tasks. That program will focus on the principles and practical applications of RCM, including the Navy's Backfit RCM efforts.[3] The latter is a process that couples RCM techniques to legacy equipment.

According to OPNAVINST 4790.16, 6 May 1998, maintenance is to be performed only when there is objective evidence of need and RCM is to be used to determine whether evidence is "objective" and what decisions are made using that evidence. SEA 04M1 has developed a Backfit RCM process,[4] which is now being used in the Surface Ship Maintenance Effectiveness Review Program. The use of Backfit RCM is appropriate for validating and improving existing maintenance requirements. These and other applications of RCM clearly show that RCM is the central building block for CBM (see Figure 2).

Figure 2. Reliability-Centered Maintenance Is the Hub of CBM



OBSERVATION: EMPHASIS ON OPEN SYSTEMS ARCHITECTURE IS IMPORTANT TO ALL CBM PROGRAMS

The recently revised DoD Directive 5000.1[5] directs program managers to consider the use of open standards in the design of all system elements (including

[3] http://maintenance.navsea.Navy.mil/

[4] *Maintenance Reengineering: The RCM Backfit Process*, Bertram D. Smith, Jr., Vice President, American Management Systems, Inc.; Kenneth S. Jacobs, Director, Surface Ship Maintenance Division, Naval Sea Systems Command

[5] DoDD 5000.1, Defense Acquisition, May 21, 1999.

mechanical, electrical, and software) for selected internal, external, physical and functional interfaces. The primary reasons for emphasizing such standards are to reduce costs and to minimize the technical risks to program design and subsequent maintenance and logistics support. The Open Systems Architecture-Integrated Diagnostic Demonstration study,[6] which looked at a number of weapon systems diagnostic strategies, came to a similar conclusion.

Our previous CBM report examined the use of open systems architecture in four CBM development programs along with the use of commercial off-the-shelf (COTS) technology and embedded hardware and software. The findings of that examination are summarized in Table 1.

Table 1. Use of Open Systems Architecture in CBM Programs

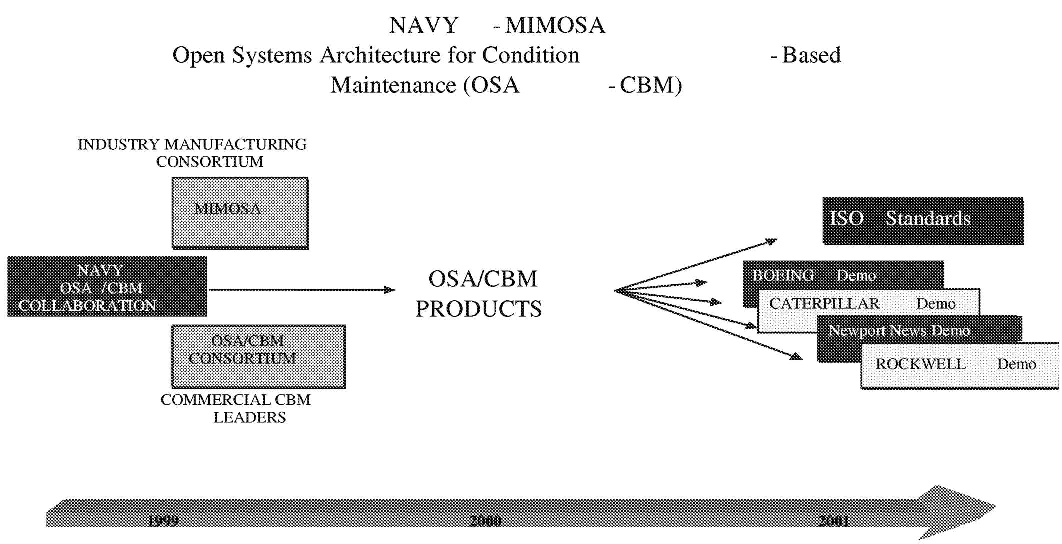
	JSF-PHM	ADIP	ICAS	IMD-HUMS
Onboard Hardware	Sensor, actuator and microprocessor intensive environment, tailored for PHM	Diesel-powered vehicles using SAE standard data bus and sensors; engine/trans anti-lock brake system control units as designed by commercial vehicle original equipment manufactures	No embedded sensors or computers in older ships. Newer gas turbine-powered cruisers and destroyers have both embedded sensors and data bus. Ship has network of computerized maintenance management system (CMMS) workstations	Mechanical diagnostics, rotor track and balance, exceedance monitoring, engine monitoring, structural usage
Onboard Software	Hierarchy of prognostic software reasoning systems	Diagnostic messages generated by the engine control units	No embedded software, except for systems mentioned above. IDAX CBM software runs on the CMMS network	Limited information
Commercial off-the-Shelf Technology	Microprocessors, interfaces to information systems	Data bus, sensors, engine control unit, message protocol	ICAS system adapted from commercial IDAX application	Limited information
Open Systems Architecture	Limited information	Yes	Yes	Use of open commercial interface standards
Logistics Linkage	Triggered by onboard prognostic software to multiple logistics information systems	Triggered by external statistical analysis within Global Combat Support System-Army (GCSS-A)	Not linked	Naval Aviation Logistics Command Management Information System)

[6] Final Report and Roadmap, January, 1999, Open Systems Approach – Integrated Diagnostic Demonstration Study, Automatic Test Systems Executive Agent Office (ATS-EAO), NAVAIR PMA-260, Naval Air Station Patuxent River, MD.

OBSERVATION: THE PEO-CARRIER INITIATIVE FOR OPEN SYSTEMS STANDARDS IS AN IMPORTANT EFFORT

The objective of the Open Systems Architecture for Condition Based Monitoring program, which is sponsored by the Office of Naval Research, is to develop and demonstrate an open systems architecture for CBM in four domains: ship systems, industrial applications, ground vehicles, and aircraft. Figure 3 shows an overview of that program. The program product is an open systems-based CBM that should continue to evolve and find widespread use in industry and DoD. The Boeing lead team of Applied Research Laboratory of Pennsylvania State University, Caterpillar, Machinery Information Management Open Systems Alliance, Newport News Shipbuilding, Oceana Sensor Technologies, and Rockwell Science Center are performing the work. The global nature of the team, combining traditionally military and commercial companies, should result in a successful development effort.

Figure 3. Graphical Depiction of the Open Systems Architecture CBM Effort



Goals

What are the goals of the CBM programs? With respect to the selected CBM programs, we asked the following:

- Are similar goals being set?
- Are the goals broad-based, strategically focused, and globally focused?
- Is progress towards the goals measurable?

In striving to answer these questions, we arrived at the following observations.

OBSERVATION: CBM PROGRAMS HAVE A WIDE DISPARITY IN GOALS

Table 2 shows some of the differences among the goals in DoD's CBM programs. Clearly, CBM programs are not setting similar goals. The Army's ADIP wants to reduce the no-evidence-of-failure rates (cannot duplicate or retest OK by other names) while the other programs do not target that goal. The JSF PHM program has set an explicit goal of reducing the logistics footprint by lowering the number of C-17 aircraft load equivalents. No other program has a similar goal. IMD-HUMS identifies cost reduction as a goal, but does not state by how much, whereas ADIP also sets a cost reduction goal and specifies a target but doesn't provide a metric to measure progress. ICAS has both short- and long-term goals. The short-term goal, and the one ICAS stresses today, is to automate the ship maintenance logbook. At the individual program level, these disparate goals are not necessarily fundamental flaws, but viewed together they suggest limited coordination among the programs.

Although perhaps not as obvious, the information in Table 2 answers the question whether DoD is setting broad-based or narrowly focused goals in its CBM programs. Both types of goals are being set; but the broad-based goals are not being uniformly embraced.

Table 2. Difference Among CBM Program Goals

Program	Goals
ICAS	Optimize operating and support costs Maximize ship readiness, reliability, safety Improve quality of life Automate ship maintenance logbook
IMD-HUMS	Improve helicopter operational readiness Improve flight safety Reduce maintenance-related costs Decrease number of dedicated functional check flight hours required to maintain the aircraft by 10 percent (threshold) with a goal of overall reduction by 25 percent (objective). Achieve a mean flight hour between failure rate of a minimum of 75.4 hours for the H-53, and 76.8 hours for the H-60, averaged across all system components Achieve a mean time to repair rate of less than or equal to 1.7 hours for the system
JSF PHM	Reduce maintenance manpower by up to 40 percent Increase combat sortie generation rate by 25 percent Reduce logistics footprint (in terms of C-17 cargo aircraft loads) by 50 percent, all relative to current strike aircraft

Table 2. Difference Among CBM Program Goals (Continued)

Program	Goals
ADIP	Reducing no-evidence-of-failure rates by 50 percent Reduce operation and support costs by 20 percent Reduce life-cycle cost for current and future systems Redesign diagnostics business process to establish an electronic link from the weapon system to the GCSS-A

OBSERVATION: NOT ALL PROGRAMS HAVE GLOBAL, STRATEGICALLY FOCUSED GOALS

Looking at the CBM goals from another perspective, Table 3 compares the established goals with the high-level expectations set in Joint Vision 2010, Focused Logistics, and similar strategic guidance. Some high-level expectations are inherent in the CBM programs, such as developing embedded diagnostics, but many of them are more technical than strategic.

Table 3. CBM Program Goals Contrasted to Strategic Expectations

Expectations for Logistics and Maintenance Transformation	ADIP	ICAS	IMD-HUMS	JSF-PHM
Agile infrastructure				X
Right-sized logistics footprint				X
Velocity-based maintenance and logistics				X
Increased responsiveness, visibility, and accessibility of logistics resources	X			X
Proactive to the maintenance and logistic needs of the warfighter	X		X	X
Lessening overall repair cycle time	X		X	X
Sharing of maintenance capabilities and facilities				
On-board platform (weapon system) sensors, diagnostics, and prognostics linked to information and decision support systems.	X			X

All programs should explicitly share some key goals. For example, right-sizing the logistics footprint is important to the concept of agile infrastructure, but only the JSF PHM program has established an explicit right-sizing goal.

Only ADIP has a goal of being linked directly to the Service's information support system. This goal is consistent with the requirements of ASLP. It also is a key tenet and implementation feature of JSF PHM, but it is not stated as an explicit goal.

OBSERVATION: ALL PROGRAMS ADDRESS COST-REDUCTION GOALS OF SOME FORM

Table 4 shows the cost goals for each CBM program, including those that would lead to lower costs, such as reducing the no evidence of failure rates in ADIP and the reduction of flight check hours in IMD-HUMS.

Table 4. CBM Program Direct and Indirect Cost-Related Goals

ADIP	ICAS	IMD-HUMS	JSF PHM
Reduce operating and support costs by 20 percent Reduce life-cycle cost for current and future systems Reduce no evidence of failure rates by 50 percent	Short Term: Reduce maintenance labor hours through automatic preparation of ship logbook Long Term: Optimize operating and support costs	Reduce maintenance-related costs Decrease number of dedicated functional check flight hours required to maintain the aircraft by 10 percent (threshold) with an overall goal of 25 percent (objective).	Reduce maintenance manpower by up to 40 percent

Metrics

In this section, we focus on how each of the programs track their progress toward meeting established goals.

OBSERVATION: USE OF PROGRAM METRICS TO MEASURE GOAL ATTAINMENT PROGRESS NEED TO BE IMPROVED

In Figure 4, we cite for discussion purposes several prospective goals and associated metrics for a CBM program. These goals and metrics illustrate the types of metrics that each of the four CBM programs should have established. Most metrics would be looked at both points in time (in the contest of a baseline, goal, or benchmark value) and as observed changes over time.

Figure 4. Representative CBM Goals and Associated Metrics

Goals	Metrics
Increased Asset Availability	Sortie Generation Rate Percent of Equipment Availability
Faster Equipment Turn-around	Sortie Generation Rate Mean Time To Repair
Decreased Equipment Maintenance	Number Maintenance Labor-hours Mean Time Between Removals
Reduced Maintenance Cost	Logistics & Maintenance Costs Cost per operating hour/distance
Reduced False Alarms	Percent False Alarms
Reduced % of False Removals	Cannot Duplicate Rate
Increased Equipment Safety	Number of accidents attributed to equipment malfunction and percent chargeper period MBTCF
Reduced Logistics Footprint	Support equipment density per unit Support Equipment weight/cube per unit Repair parts stockage per unit Repair parts weight/cube per unit Number of C-17 Load equivalents
Customer Satisfaction	Periodic Satisfaction Survey

Metrics provide the tools for evaluating progress toward achieving goals. For each goal in a CBM program, a corresponding metric should also be available. The importance of good metrics cannot be overstated: without them, program effectiveness cannot be gauged. Shown below are the goals and metrics for each of the four CBM programs. As Table 5 shows, the goals and metrics vary considerably among the programs. In particular, ADIP has few well-defined metrics, while the ICAS program has only one metric. The aircraft programs employ more explicit goals and metrics, with JSF PHM planning having the most extensive. The overall effect of having only a few metrics is an inability to assess program effectiveness.

Table 5. CBM Goals and Metrics by Program

Program	Goals	Metrics
ADIP	Reduce no-evidence-of-failure rates by 50 percent Reduce operating and support costs by 20 percent Reduce life-cycle cost for current and future systems Redesign diagnostics business process to establish an electronic link from the weapon system to the GCSS-A	No program-level metrics; metrics exist for individual weapon system programs for development and monitoring
ICAS	Automate ship maintenance logbook Optimize operating and support costs Maximize ship readiness, reliability, safety Improve quality of life	Logbook administrative time: (steaming hours) X (18 log takers) X (20 minutes/log)
IMD-HUMS	Improve helicopter operational readiness Improve flight safety Reduce maintenance-related costs Decrease number of dedicated functional check flight hours required to maintain the aircraft by 10 percent (threshold) with an overall goal of 25 percent (objective). Mean flight hours between failure rate of a minimum of 75.4 hours for the H-53, and 76.8 hours for the H-60, averaged across all system components Mean time to repair less than or equal to 1.7 hours for the system	Maintenance flights, planned flight hours vs. actual flight hours Mean flight hours between failure Mean time to repair Fault detection/fault isolation efficiency False alarm rate

Table 5. CBM Goals and Metrics by Program (Continued)

Program	Goals	Metrics
JSF PHM	Reduce maintenance manpower by up to 40 percent Increase combat sortie generation rate by 25 percent Reduce logistics footprint (in terms of C-17 cargo aircraft loads) by 50 percent, all relative to current strike aircraft	Percent of correct automatic detections, of detectable failures Percent of correct automatic isolation of correct detected failures Mean time between false alarms Remaining useful life of component safety Remaining useful life of component maintenance Direct maintenance man-hours/flight hour Direct manpower spaces/aircraft Low observable restoration time Mean time between unscheduled maintenance events Mission reliability Mean time between operational mission failures Mean time between critical failures Mean time to repair Mean time between removals Sortie generation rate

Resources

A major risk to CBM programs is sporadic funding. All four of the CBM programs have significant unfunded requirements. JSF PHM is part of the JSF acquisition program, so it can be treated separately; the other programs must be funded on their own merits, which suggests that achieving their long-term objectives could be at risk.

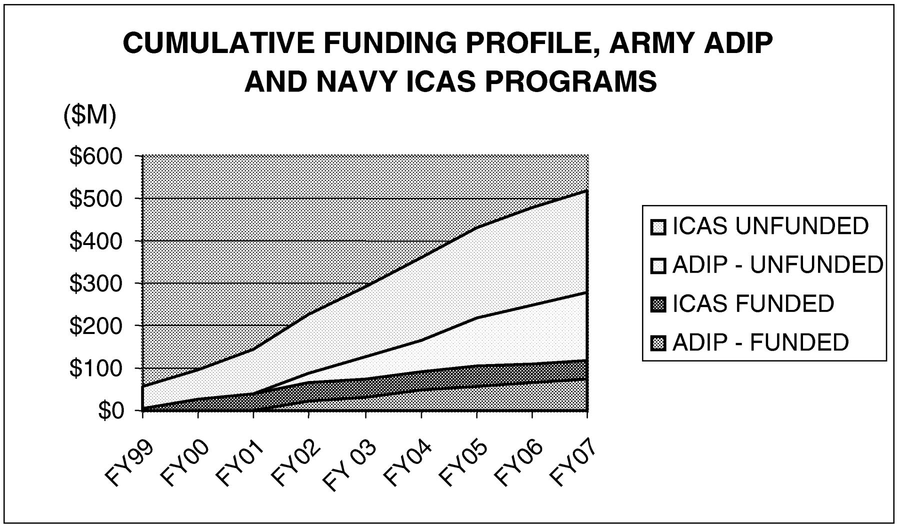
OBSERVATION: THE ADIP AND ICAS PROGRAMS ARE SIGNIFICANTLY UNDERFUNDED

According to Figure 4, ADIP and ICAS are substantially underfunded. Although the ADIP budget has been recently increased, the program continues to have a significant backlog of unfunded requests.[7] Its unfunded requests, not including the

[7] ADIP System Review Summary, FY 00 – 07 POM, Unfinanced Requirements, March 2000.

helicopter programs exceeds $150 million through fiscal year (FY) 07. The ICAS program also has significant underfunding issues, including training, future ship installations, and ongoing technical support. Its unfinanced requirements for the period FY00-FY07 exceed $190 million.[8]

Figure 4. ADIP and ICAS Funding Profile Through FY07



In total, ADIP and ICAS are currently funded at about 23 percent of their stated requirements from FY00 through FY07 (about $119 million out of more than $500 million). As a result, neither program may be able to achieve its objectives.

Payback

As part of our review of the four CBM programs, we also examined their cost-benefit and return-on-investment analyses. We found that it is still too early to judge the paybacks of these programs. The issue of program paybacks is further compounded by the absence of program metrics.

OBSERVATION: THE PAYBACKS FROM CBM PROGRAMS ARE NOT YET WELL DEFINED; PRELIMINARY RESULTS ARE ENCOURAGING, BUT LIMITED

In our examination of paybacks, we focused on both the qualitative and quantitative benefits. In some cases, we characterized these benefits as observed (based on preliminary program results); for others, we considered them as forecasts only.

[8] ICAS Budget Submission, March 2000.

ADIP

- Observed Quantitative Benefit

  Improved readiness rates (pending publication of field beta testing results)

- Observed Qualitative Benefit

  Achieved highest battalion readiness rate in mechanized infantry brigade for 1/14 FA at National Training Center during Brigade rotation for 1st Infantry Division; also avoided two instances of potential catastrophic vehicle failure (fire due to faulty battery and alternator) at National Training Center

ICAS

- Observed Quantitative Benefits

  - Saved approximately 15,000 man-hours annually by automating 45 percent of DDG51 logs

  - Saved approximately 11,000 man-hours annually by automating 30 percent of CG47 logs

  - Saved approximately 6,500 man-hours annually by automating 11 percent of DD963 logs

JSF-PHM

This program is just entering Engineering and Manufacturing Development, so its cost-benefit analyses are still pending.

- Forecast Qualitative Benefits

The program has at least 13 prognostic technology maturation efforts underway on the propulsion system alone, some of those efforts, such as the oil debris monitoring technology, will also benefit other weapon system programs.

IMD-HUMS

- Forecast Quantitative Benefits[9]

For the H-53 and H-60 aircraft:

  - 13 percent reduction in scheduled maintenance because of accurate flight hour recording

[9] Engineering judgement used to develop benefit factors for cost benefit analysis; results used to determine cost savings associated with full IMD HUMS functionality.

- ➤ 10 percent reduction in total aviation depot-level reparable/consumable costs because of fewer vibration-related maintenance actions
- ➤ 6 percent reduction in depot costs
- ➤ 2.8 percent reduction in flight hours because of fewer functional check flights on H-60; 3.7 percent on H-53

◆ Observed/Forecast Quantitative Benefits

Improved flight safety

Qualitative Versus Quantitative Benefits

Our earlier study pointed out the need to assess both the qualitative and quantitative benefits of CBM programs. In that report we made the following observations regarding military versus commercial vehicle operational failure expectations (these observations apply to all DoD equipment with commercial counterparts).

The risks associated with commercial breakdowns are almost exclusively financial, while those associated with military equipment are very different. If the equipment is being operated in a training environment at home station, the risks of serious operational constraints are minimal. The difficulty arises when units are deployed, whether within the continental United States (CONUS) or outside the CONUS (OCONUS).

- ◆ Units deployed away from home station but within CONUS that encounter unscheduled maintenance problems clearly would have their operational experiences affected, but the impact would be relatively minor.
- ◆ Units deployed OCONUS have high utilization rates and little redundancy. Unscheduled, unpredicted equipment breakdowns in this environment can have catastrophic results; personnel could be at risk, cargo could be at risk, and entire missions could be jeopardized.

The costs associated with these risks, particularly those incurred OCONUS are not easily calculated. What is the cost of a cancelled operation? What is the cost of severely degraded capability when one vehicle, for example, fails and another must be taken off the mission to help recover the first? All too often we try to make informed judgments regarding advantages and disadvantages of particular courses of action. We have a variety of analytical tools at our disposal when we have to make choices involving quantifiable elements. Unfortunately, when dealing with the types of uncertainty associated with CBM programs, many of the benefits cannot be quantified.

Most of the return on investment analyses for CBM programs show return multiples between 2 and 4.[10] This rate of return is much lower than that found in industry, which routinely reports multiples between 7 and 10.[11] In today's technology rich investment environment, can DoD expect such rates of return from its CBM investments?

Several government, commercial, and vendor-proprietary cost-benefit models will roll up forecast cost-avoidance figures. Those models all use similar inputs, but with different assumptions about the inputs. When calculating the return on investment, it is difficult to estimate the savings of an avoided failure, and in many cases these savings are very optimistic, so many return rates are suspect from the start.

Return rates, however, be useful to examine hypothetical savings given a level of investment. This approach works backward from the return rate to determine a given level of investment necessary to achieve expected savings. It can be used as a common sense check on funding levels for CBM.

For example, we stated that unfunded requirements dominate both ADIP and ICAS. If those requirements were funded, and if those programs achieved a nominal return rate, would the return generate the cost avoidance savings being forecast for Joint Vision 2010 scenarios? According to the Office of the Secretary of Defense, the Army, Navy, and Air Force will spend the following amounts on Operations and Maintenance in FY01:[12]

- Army–$18.9 billion
- Navy–$22.6 billion
- Air Force–$20.7 billion.

Using the above Army figure as a basis for projecting costs savings, the Army's CBM programs project a 20 percent cost reduction in operation and support costs. For a crude estimate, we assume approximately one third of the Army's budget figure can be attributed to maintenance and repair parts (the other major budget components are mobilization, training and recruitment, and administrative and service commitments). At a 20 percent savings rate, the total savings would be about $1.25 billion if ADIP achieves its goal. At a rate of return multiple of 4, a savings of $1.25 billion would require roughly a $312 million investment. Since the total ADIP budget is approximately $120 million (with approximately $100 million unfunded), either the return multiple or amount of investment must be increased.

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[10] The notation "x" refers to the multiplication term "times."

[11] John Mitchell, President, MIMOSA, Producer Value – A Proposed Economic Model for Optimizing Equipment Life (Asset) Management and Utilization, May 1998.

[12] Office of the Secretary of Defense, Operation and Maintenance Overview, FY2001 Estimates, March 2000.

This simple analysis illustrates that the current level of investment for the Army’s CBM program may be inadequate to achieve stated goals. A similar analysis shows identical results for the Navy’s CBM program.