NAVY RESEARCH PROJECT

A Projection of Moore's Law
and
Recommended Approaches to
Manage and Mitigate Risks

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Direction & Approach

CAPT Gib Kerr, USN, PMS 435, is currently faced with the challenge of managing the cost and schedule impacts to submarine and surface ship procurements driven by the rapid turn-over of electronic technologies. These impacts include the costs and schedule implications of managing parts obsolescence on high technology Navy systems. This obsolescence occurs as commercial electronics manufacturers replace current component production with newer, more capable products. Navy ships are increasingly composed of complex electronics technology and rely almost totally on the commercial electronics industry for its parts. During the period required to develop and produce a Navy ship and its major systems, the electronic components will have gone through several life cycles, creating a tremendous workload for the ship's prime and subcontractors. Replacing these components over the life of the platform, when those components are no longer available commercially, magnifies the obsolescence impacts.

CAPT Kerr specifically asked forr students from the Electronics Seminar to study the phenomena of Moore's Law, the industry bench mark for the rate that electronic chip capability advances, and to provide a projection of how long this trend will continue. In addition, he asked the Electronics Seminar to assess the impacts to the commercial world's costs and schedules, and in turn, the cost and schedule impacts to Government systems.

Two students divided the work into two parts. The first part entails a detailed study of Moore's Law through discussions with companies, industry associations, Government, and academia. The second area focuses on determining how Government and industry currently manage obsolescence, or frequently referred to as Diminishing

Manufacturing Sources and Material Shortages (DMSMS or DMS for short). Government and industry experts representing some of the latest weapon systems and commercial systems were asked to describe their DMS programs as well as their costs. This report summarizes these findings and identifies a number of experts, should CAPT Kerr and others on his team desire additional information.

Executive Summary

Moore's Law: The number of transistors that can be placed on a micro-circuit doubles every 18-24 months, resulting in a rapid turnover in generations of microcircuits. There are almost as many opinions about the how long Moore's Law will be applicable as there have been technological advances since the Law was first annunciated in 1965. The majority of industry experts, however, believe that the physical limits of silicon based advancements will be reached by the end of the decade. Microelectronics obsolescence will remain a challenge as industry and academia alike are hard at work on marketing post-silicon applications. New atomic compounds, such as gallenium arsenide and ferritin, may replace silicon substrates within integrated circuits, while entirely new technologies like quantum computing may transform the entire industry. The point is that while Moore's Law will end relatively soon, innovation will not--and DoD program managers (PM) will still have to manage obsolescence.

What is obsolescence? As electronic semi-conductor, sub-component, and component manufacturers rapidly develop new, more capable products, the older products are no longer profitable to build and sustain, particularly at the small quantities the Government purchases. This forces management to "buy-out" up front, all the parts needed for the life of the program, or to redesign/re-qualify the parts, or to find other sources. For large systems, such as the F/A-22, hundreds of parts become obsolete each year and are referred to as Diminishing Manufacturing Sources and Material Shortages (DMSMS or DMS for short). DMS impacts not only acquisition and support costs, but, mission capability and war readiness as well.

Industry and Government Management Practices: The Air Force, Navy, and Army DMS Program Offices are responsible for distributing DMS guidance and providing expert support to weapon system Program Offices. They work to insure each program office has a trained, knowledgeable DMS focal point armed with tools and databases to help manage DMS issues. We strongly recommend every weapon system program office contact their service's DMS Program Office as they begin preparations for the development phase and periodically throughout the program's lifecycle. For industry, the Government Electronics Industry Association (GEIA) has developed a comprehensive guidance document, GEB1 (www.dmea.osd.mil/gebl paper.pdf) that provides a thorough overview of DMS problems and potential solutions. GEB 1 stresses a combination of proactive and reactive measures to minimize the cost and schedule impacts resulting from DMS. GEB1 is well worth the Government program office leaders' and DMS focal point's time to read and understand.

Case Studies: We selected programs that were comparable in size' and complexity to Capt Kerr's programs, and whose contacts were readily available for consultation. These included the F- 15 Radar Upgrade, the F/A-22, the Joint Strike Fighter (F-35), and the AEGIS DMS Program. Air Force and Navy program offices are moving toward the commercial approach to managing DMS. This means delegating responsibility to (and paying) the prime contractor to manage the bulk of the DMS program. This includes establishing proactive measures, such as designing parts and systems with architectures that are more resistant to DMS; i.e., they are backward compatible, and selecting components at the front end of their life cycles, thus extending the time before they become obsolete. The JSF program has gone one step further by authorizing subcontractors to change and upgrade parts as long as they conform to form, fit, function, and interface requirements, plus, incentivizing contractors to upgrade components to achieve affordability and supportability goals. Prime contractors direct the suppliers to provide advance notice for parts or components that they have decided to no longer produce. Advanced notification allows the suppliers and primes time to search for alternative measures to obtain parts. Prime contractors have established databases for their DMS parts and search other databases, including industry associations, so that synergies can be obtained to help resolve DMS issues. Both commercial and military prime contractors have developed efficient and effective procedures for tracking, reporting, and resolving DMS issues and risks.

DMS Management Costs: Annual DMS management costs for major programs such as the F/A-22, run approximately $100M/year. This cost includes the program management, Integrated Product Teams (IPT), and supplier costs to resolve hundreds of DMS cases. DMS costs are much lower for fielded systems, such as the F-15, or, for systems early in development, such as the JSF. It is difficult to determine the equivalent DMS costs in commercial industry because they delegate nearly total responsibility to their suppliers, who have life-time responsibility for supporting their products, i.e., as long as there are aircraft in the field, the supplier is responsible for insuring its systems are supported. In these instances the DMS costs are included into the component "price". In our professional judgement, the more commercial like the Government can make its DMS program, the less it will cost and less risk will be experienced.

Analysis of Moore's Law

Moore's Law was coined back in 1965 when Intel co-founder Gordon Moore observed that the semiconductor industry would be able to double the number of transistors on a single microprocessor every 18 to 24 months. As the number of transistors doubles, so does the speed. This rate of change has occurred with such consistency that it has become the standard that semiconductor companies, or "chipmakers", have almost religiously ascribed. And the result, while beneficial to application entrepreneurs and public consumers, has exacerbated the weapon system business. In addition to long development and production lead times, DoD PMs must also account for system sustainability and multiple generations of technological advances over the typical decades-plus life of a weapon system (see attachment 1). Faced with an increasingly irrelevant DoD customer base (Defense accounts comprise only .03 percent of the US semiconductor business), the industry finds it unprofitable to maintain a repair and replacement infrastructure for legacy technology.

The situation is further confused by conflicting industry pronouncements of the future of Moore's Law, i.e., that reduction in transistor size and corresponding microprocessor integration issues will soon reach their physical limitations. If true, how soon? And how does this possibility effect DoD PM's strategy when choosing

[1] Guest Lecturer from the University of Maryland, Briefing to the Industrial College of the Armed Forces, Feb 2003.

contractors, factoring in supportability, and forecasting operational age limits of weapon systems?

Engineers at major semiconductor companies like Intel and Advanced Micro Devices currently continue to prove Moore right. Transistors have shrunk to less than 130 nanometers (run) and silicon channels to 4 run, down from 15 nm last year[2]. Prime manufacturers anticipate cracking the 100nm barrier this year and surpassing 70 or even 50 nm by 2008 [3] In theory, there's little to stop engineers from pushing the envelope all the way down to the atomic limits, i.e., 1.4 nm for a molecule of silicon dioxide or .27 nm for a single atom of silicon. So could Moore's Law continue on unchecked for another 50-plus years? Due to associated physical limitations, most industry experts think not.

As the transistor sizes continue to shrink, the increased concentration of dopant atoms will become too great for the silicon's crystalline structure to contain the atoms and thus result in performance-crippling leakage. Another root cause of leakage involves the ever-shrinking size of the transistor gates; reputed projections of 9nm gates, while a potential boon to the speed of the microprocessor, will likely become too thin to prevent electron leakage. Finally, the heat emitted by the prodigious energy transfers between billions of electrons associated with sub-50 nm transistors theoretically approaches the amount generated at the sun's surface.5

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[2] Lawrence Kren, "Moore's Law Alive and Well," Machine design, November 7, 2002, Volume 74, Issue 21, p. 56
[3] Brad Stone, "Upholding Moore's Law," Newsweek, March 25, 2002, Vol. 139, Issue 12, pp. 46-47
[4] Steven M. King and Matthew C. Verlinden, "Seeing Beyond Moore's Law", Semiconductor International, July 2002, Volume 25, Issue 8, pp. 50-60
[5] Guest Lecturer, Feb 2003

The shear cost of microchip fabrication facilities, aka fabs, presents another prohibitive challenge.[6] Based on the technology required to further decrease transistor size, fab costs are estimated to run into the $5 *billion* range - certain to engender caution in the capital investment plans of almost all chip manufacturers.[7] Several industry experts also doubt chip manufacturers will be readily able to transition past the current optical lithography process. While experiments in extreme ultraviolet lithography and electron projection lithography both show promise for inserting the future generation billion-plus transistors onto chips, engineers still must develop breakthroughs to interconnect them. Again, the infrastructure required to activate these new lithographic processes, including all new plant, equipment, and entirely revolutionized metrology tools, will add to the increasingly exorbitant costs of making a fab.[8]

Silicone Solutions: Obviously engineers aren't sitting still in the face of these challenges. The world's leading semiconductor manufacturer, Intel Corporation, believes it will continue to shrink transistors, at least to 50nm, merely through a silicon-based process termed hyperthreading. Hyperthreading is a means of splitting the energy of a single transistor without actually dividing the chip, i.e. enabling it to simultaneously burn a CD and edit a video.[9] To get around the heat problem, they have designed (and may soon develop/refine) a family of "terahertz" transistors. The flagship Trigate terahertz

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[6] Brian Fuller, "Moore's Law on Target for 25 Years," Electronic Engineering Times, March 15, 2002, p. 26

[7] Guest Lecturer, Feb 2003

[8] Semiconductor Industry Association, "Summary of the International Technology Roadmap for Semiconductors", February 6, 2002, pp. 1-4

[9] Stone, p. 47

transistor will wrap around three sides of the diodes, or gates, as opposed to simply covering them, thereby significantly lessening heat emissions. to

Innovations and a new paradigm: Whether it's 5 years or 15, the various physics and financial-related difficulties will render the current Moore's Law obsolete, or at least fiscally untenable. Semiconductor manufacturers refuse to cry uncle, however, and a brief look at developing non-silicon technologies is in order. First, engineers are exploring ways to enable molecular electronics to improve transistor functions. Similar in concept to hyperthreading, the idea involves layering molecule-switch devices onto conventional silicon transistors and boosting their capability." In some respects, this innovation represents a part silicon, part synthetic hybrid solution extending the limits of Moore's Law.

More revolutionary are planned attempts to replace silicon as the primary transistor component. Gallium arsenide and germanium are equally touted as silicon substitutes for transistors in the 10 nm range.[12] Several manufacturers are experimenting in synthetic chemicals[13] and plastics with the hope that they can simultaneously achieve full transistor capability and zero leakage. Uniquely interesting are forays into biotechnology. Some companies are investing in ferritin, a protein found in both plants and animals (to include humans). Their goal is to grow magnetic nanoparticles that will

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[10] Cade Metz, "A Fascinating Future in Chip Design," PC Magazine, Feb 1, 2003, Vol. 22, Issue 2, pp. 122-123

[11] Patricia Panchak, "Molecular Electronics," Industry Week, December 2002, Vol. 251 Issue 12, p. 60

[12] Metz, p. 123

[13] Alan E. Kaloyeros et al, "Exploiting Nanotechnology for Terahertz Interconnects," Semiconductor International, January 2003, Volume 26, Issue 1, pp. 56-59

eventually "combine digital, analog, and microelectromechanical particles all on a single chip,"[14] and thereby increase capability by orders of magnitude.

Of all the proposed initiatives to further shrink transistors, the most revolutionary and risky involve subatomic application. From the previously mentioned molecular transistors to using carbon-based nanotubes as gates in the new chip design, scientists strive to isolate parts of atoms for use in future transistors.[15] But the truly new paradigm of quantum computing as the basis of chip design is wherein lies the greatest potential.

In essence, quantum computing encompasses the theory that split atoms can work as "quantum switches" and simultaneously rest at both on and off, i.e., represented by 1 and 0 (as opposed to conventional switches which can represent *either,* but not both 1 or 0). The practical result would contrast the example of three ordinary switches that could store any one of eight patterns, versus three quantum switches that could hold all eight patterns at once.[16] If this holds true, the theoretical potential for transistor power is staggering. Even further optimistic projections hold out for 0.25 nm size transistors (smaller than a single silicon atom) created through a process called subatomic channeling, where carbon nanotubes found within living systems are configured to ballistically transport almost a trillion electrons across a single chip.'[7] If and when these concepts are realized, the demise of Moore's Law, will be a negligible footnote in the history of electronics.

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[14] Nicolas Mokhoff , "Nanotechnology Will Even Out Semi Cycles," Electronic Engineering Times, November 25, 2002, p. 20
[15] Rob Fixmer, "Moore's Law & Order," eWeek, April 15, 2002, Volume 19, Issue 15, pp. 39-40
[16] Joseph. F. Traub, "The Next Big Thing," Scientific American, February 2003, Vol.288, Issue 2, pp. 88-89
[17] Kaloyeros, p. 59

Impact of Moore's law on DoD weapon system development: So what do all these varied predictions of the limits to Moore's law and the semiconductor industry's attempted workarounds mean for Defense Department PMs? The wide range of industry opinions project current silicon-based transistor development to reach physical and/or financial limitations in 4 to 25 years, with the largest cluster of experts hovering around the 2010 timeframe. Therefore, PMs should expect approximately seven more years of technology upgrades (or 2-3 generations) involving integrated circuits. And even as Moore's Law begins to run its course, it's safe to assume researchers will find alternatives to silicon-based transistors. Despite serious transformation efforts, DoD acquisition will still likely take years between concept development and operational fielding. Therefore at first glance, it appears there's little PMs can do to counter the vicious cycle of lengthy weapon system development times, technological breakthroughs, and DMS. Fortunately, this is not entirely the case.

By most estimates, including Moore's, there will be a significant gap between the halt of silicon-based transistor shrinkage and assembly line manufacturing of synthetic, organic or subatomic transistors. How many years the gap will encompass is anyone's guess, but estimates indicate the timeframe somewhere between 2028-2050.[$] Along the way, the industry will make improvements on the margins, but there just may be a chance for the Defense Department to catch up. By wisely using the 2010-2028 window, PMs can design weapon system contracts with vendors who concurrently sell silicon-based ICs and invest in state-of-the-art alternatives, betting that these companies will be too capital-dependent upon the silicon infrastructure to readily forego system sustainability.

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[18] Jack Robertson, "Moore's Law Namesake Predicts IC Density Growth Could Slow", EBN, Jul 15, 2002, p. 10

While the decade of the 201 Os should allow a degree of temporary respite from transistor advancements, if there's anything the previous 38 years of Moore's law have taught, it's that you can't totally bet against it (in concept at least). Thus, PMs will also have to restructure the ways in which they manage DMS.

Government and Industry Management Practices

GEB 1

Under the umbrella Government Electronics and Information Technology Association (GEIA), federal and industry experts outlined several technological and program management techniques to offset DMS. While the following general prescription won't apply to each and every DoD weapon system, several key case studies prominently highlight critical practices that mitigated this problem--in turn ensuring longer system performance and reducing taxpayer burden.

Arguably the most important goal for DoD PMs and contractors alike to aspire to is to be proactive! The period when a weapon is well underway in production or even operational is *not* the time to realize that DMS threatens the system's sustainability. By artfully combining thorough industry research and anticipatory tactics, the government can get the jump on the five major aspects of obsolete technology.[19]

Predominant effects of DMS:. Any brief list of the primary difficulties surrounding electronics within Defense weapon systems must place the non-availability of parts at the top. As contractors, subcontractors and researchers all transition to new technologies, the "simple" aspect of locating obsolete components needed to repair still-

[19] Henry Livingston, "Diminishing Manufacturing Sources and Material Shortages (DMSMS) Management Practices, pp. 2

operational systems becomes increasingly difficult and expensive. Inadequate system partitioning, usually frequent in closed proprietary architectures, is another leading culprit. Too often, the obsolescence of even minor components, within a tightly meshed design, will require wholesale replacement of the *entire* major component or system. This architecture issue cannot be overemphasized, even when reacting to smaller, selective modifications; while potentially readily available and inexpensive in and of themselves, the insertion of certain modern components can distort the system's overall configuration and result in further integration challenges. The widespread use of commercial off the shelf (COTS) components, while rightly hailed as a financially efficient development strategy, can nevertheless prove problematic when trying to upgrade military weapons during their extended lifetimes. And even the software which runs the system and components is not exempt from DMS, as programming languages and interfaces are also eliminated from supplier inventories.[20] Making matters more difficult for the PM, the problems sketched above seldom occur in isolation. Therefore, aggressive and strategic development plans are required.

Open and independent architectures: Perhaps the first commandment of a counter-DMS development strategy is to ensure an open system architecture that does not bind the entire weapon's development and maintenance to any individual component. Although difficult to ensure with traditional proprietary, closed military systems,[21] the recent focus on COTS-based components and mergers of former competitors allows PMs and contractors increasing access to broad technologies. The result is the opportunity for separate, integrated and most of all *common* hardware and software modules. Subsequent

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[20] Ibid, p. 3
[21] Ibid

redesigns and replacements will be focused on the specific obsolete component and thus preclude the need for total system overhauls.

Field programmable gate arrays: One of the costlier ramifications of obsolete microelectronics hardware is the requirement to totally redesign the digital functions that reside on the old ICs. Advancements in Programmable Logic Devices and computer Aided Engineering tools have yielded the ability to modify IC designs without always having to reconstruct the chip. Field Programmable Gate Arrays (FPGAs) combine the integration of Application Specific ICs (ASIC) with pre-programmed logic to essentially write over existing IC gate devices[22] The result is that many components can be upgraded vice replaced, thus reducing the overall DMS costs.

Software specific solutions: PMs also need to insist on software development that enables execution independent of the host platform. By obliging contractors to employ portable code at the weapon system's inception, or at least migrate to portability during the early stages of production, government can avoid having to totally redesign and replace software when hardware components become obsolete. Industry experts contributing to the GEIA study emphasized that pre-production portability is desired, as changing source code midstream in a system's life will often prove too costly.[23]

Other solutions: GEB 1 provides a thorough description of the various alternative solutions to DMS issues. One tactic the government has increasingly taken advantage of is the aftermarket producer category. Identifying and contracting with firms that will deliver components after their technology has passed by is a relatively low cost strategy. Component substitution, while often a challenge to integration, and more

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[22] Ibid
[23] Ibid, p. 4

expensive than finding an alternative source, is another approach used to mitigate DMS. And when workable substitutes are unavailable, system developers often turn to emulation. By designing and building replacements for obsolete ICs, engineers "emulate" the electronic make-up of the chips without the heavy expenses incurred in a fab.[24] Obviously, there is significant risk as the emulated circuits must guarantee the same level of performance and be manufactured in sufficient numbers to achieve economies of scale that offset the design costs. As with all of these options, emulation represents a potential workaround to the problem of DMS. Arguably the *best* approach is to construct the original contract in a manner that anticipates, and subsequently manages, the inevitability of DMS. This acquisition strategy contracts suppliers to proactively support their products for the life of the weapon system, and is starting to be factored into recent DoD programs.

Air Force and Navy DMS Program Office Guidance

The Air Force created a Diminishing Manufacturing Sources and Material Shortages (DMS) program office (AFRL/MLMT) at Wright-Patterson AFB, Ohio. For the Navy, NAVSUP in Mechanicsburg, PA was the focal point for DMS program management. However, effective 21 March 2003, their DMS Program management has been transferred to one of its field activities, the Naval Inventory Control Point (NAVICP, a one-star Command), under Navy Transformation initiatives. The details of this migration and the specific location of the DMS function within NAVICP are currently being negotiated. The Navy's DMS program office has a similar role as the Air Force's DMS office; however, with less funding for planning, training, or coordination

[24] Ibid, p. 8

activities. The Air Force's DMS Office's role is to serve as Program Managers responsible for:

- recommending **policy** and procedures at the appropriate levels of the Air Force and DoD.
- ensuring i**mplementation** of DMS programs and procedures at the Field Activities located at the Air Logistic Centers and at System Program Offices (SPO) located at the Product Centers.
- interfacing with various organizations within Government (OSD & all services, DLA, JLC-GIDEP, DMEA) and industry for information sharing and to participate in working groups targeted to problem identification and resolution.
- providing **tools and limited training** to the Air Force DMS community.

Policy: DMS related policy and guidance flows from DoD 4140.1-R at the top level down to Air Force Material Command (AFMC) Instruction 23-103 which governs the DMS activities for all Air Force field activities and program offices. For the Navy, NAVSUPINST 4800.6A (27 Mar 2001) is the program directive that implements DoD 4140.1-R mandates for Navy DMS management. In summary the policy directs organizations: to have a DMS focal point, to use the GIDEP alert notification system, and that AFRL/MLM serves as the focal point for gathering of the Air Force's future requirements that are determined to be obsolete. If the SPO has delegated support responsibility to a prime contractor, then the SPO needs to insure they receive full program DMS management data to oversee performance and to be prepared in the event that the contractor is no longer responsible for DMS management. The DMS Program Office has developed the Case Resolution Guide to provide a greater understanding of the steps involved in identifying and addressing DMS issues. It is described under the "tools and training" section below.

Implementation: The DMS Program Office works with Acquisition and Logistics DMS Managers to implement the management planning and processes to insure they manage "proactively" vs. "reactively". Some program offices, like the F/A-22 and the JSF, have delegated DMS management responsibility to their contractors. Other programs, such as the F-15, maintain management responsibility within the Government. Either way, the DMS Program Office will help assess DMS program needs based on program complexity, budget, and management philosophy. Based on their needs, specific DMS programs and procedures can be selected and implemented.

"Reactive" DMS programs are characterized as performing limited up-front planning. The bulk of their activity is responding to notices from suppliers or other agencies, often with limited lead-time, that parts will no longer be produced. Then they initiate a series of activities to resolve the problem. Over the life of the program, the numbers of problems will multiply and the extent of the problems will become greater, not only becoming more difficult and costly to manage, but also resulting in degraded mission capability. On the other hand, "Proactive" managed programs require significant upfront investments and planning, not only establishing contacts, but creating design processes and architectures to minimize the occurrence of DMS events and to be postured to readily mitigate their impacts. Proactive processes will help reduce total ownership costs and schedule risks improving mission readiness.

Tools and Training: The DMS program office maintains a number of tools and provides training and assistance to help a program become "Proactive". In addition, the

DMS "Case Resolution Guide" describes the four phases of resolving a DMS issue. These phases include:

1) Identification and notification: This involves establishing contacts with part and equipment manufacturers, the Defense Supply Center, Columbus (DSCC), Applications, Programs, Indentures (API) Data Base alerts, and the GIDEP alert system.

2) Verification: This involves using various databases and contacts to determine the extent of the problem. First, it must be determined if the affected item is used on your system, and if so, where, and how much time before parts deliveries are affected.

3) Options Analysis: The information collected is compiled and options are developed, such as performing a partial or total "life of type" buy out, redesigning the parts, and developing another source. Constraints, including the availability of time and funding, are identified and used to compare the options.

4) Resolution Selection and Implementation: This involves implementing the selected alternative course of action. For fielded systems, the inventory control point (ICP) is typically responsible to manage the implementation.

The DMS Case Resolution Guide (like GEB 1) provides detailed descriptions of common alternative courses of actions and their non-recurring and recurring cost impacts, schedule impacts and the lasting effect of each option.

In conclusion, visiting with your service's DMS program office is strongly recommended at the front end of any DMS planning effort. They provide a wealth of information, experience, and tools to help a program get off to a good start. Even if the weapon system program office chooses to delegate the majority of the DMS responsibility to the prime contractor, it is imperative that the Government fully understand this function in order to create the best, long term value for the tax payer. The various service focal points are as follows:

- Air Force: Mr. James Neely, AFRL/MLMT, 937-904-4374 and Monica Poelking, AFRL/MLME, 937-904-4352
- Navy: Jack Speaker, NAVSUP-Command Science Advisor, 717-605-3405
- Army: LtCol Alan Lee, AMCRD, 703-617-9629 and Leo Garcia-Baca, AMCRD, 703-617-5109

Commercial DMS Management Practices

Background: Steve Tanemura of Boeing Phantom Works (253-773-6038) led a detailed study comparing commercial and military DMS management practices and presented his results at the DMEA 2000 conference. Steve's purpose was to "identify potential synergy areas" where both sides could benefit. This section provides a brief summary of his findings concerning how commercial companies manage DMS issues in comparison to military programs.

The study assessed Boeing's military programs, their Boeing Commercial Airplane Group (BCAG-System integrator of commercial aircraft), the Boeing Commercial Avionics Systems (CAS-in house electronic subcontractor), and Boeing Electronic Systems and Missile Defense (ES&MD-design/fabrication of military electronics). He identified and evaluated the DMS responsibilities and processes of BCAG and those responsibilities and processes they delegated to their suppliers.

Findings: BCAG delegated much more DMS responsibilities and duties to their suppliers than Military DMS program managers delegate. BCAG maintains emphasis on those DMS issues that effect system level performance. BCAG provides greater flexibility to their supplier community in order to simplify DMS management.

Typical commercial airplane practices: BCAG negotiates multi-year contracts lasting 5-10 years with their equipment suppliers, establishing prices for the entire duration. Their suppliers fund all support related management activities, including DMS, through overhead accounts. BCAG negotiates maintenance agreements requiring the suppliers to "support the equipment in the field as long as one airplane is still flying".

Product Redesigns: If the supplier believes a redesign is the appropriate option to deal with a DMS issue, it will provide its recommendation to BCAG. BCAG has final approval rights on Category 1 changes, which I believe are similar to Military class 1 engineering changes--affects form, fit or function. Otherwise, the supplier is free to make changes. If the supplier decides to incorporate a product improvement to resolve a DMS issue, any associated cost savings are shared between the prime and the supplier. All changes are funded through the supplier's overhead accounts.

In the commercial airline industry, the airline company (customer) is rarely involved in DMS management activities, unlike military customers who control funding, determine maintenance concepts, make final decisions on equipment redesigns and establish other requirements as necessary. The aircraft systems integrator has more flexibility to work DMS issues in the commercial world.

Military business practices: Most military contracts are for a single year. Support or maintenance contracts are separate from production contracts. DMS resolutions are usually funded through ECP activity. It is more difficult for military suppliers than commercial suppliers to develop the necessary DMS management structure, to implement a long-term DMS vision, and to fund multiple years of parts in one budget cycle.

Similarities: Both military and commercial companies rely heavily on DMS tools and databases. Both have policies and guidance promoting pro-active planning/preparation and reactive problem resolution procedures. Military prime contractors are starting to become less involved in managing DMS issues with supplier equipment and are moving more toward the commercial approach. Both military and commercial companies promote sharing information and best practices through DMS related conferences and teaming relationships.

Tanemura identified many opportunities for achieving synergy between the commercial and military DMS management practices; however, due to unique constraints on military programs, some may be difficult to achieve. In addition it appears that many of these may be appropriate for Boeing commercial and military Divisions to cooperate, as opposed to organizations belonging to different companies. Some opportunities include:

- Developing a standardized subcontractor parts management approval process that addresses DMS management requirements.
- Establishing a common DMS database and maximizing information sharing.
- Creating DMS forums to promote commercial and military information sharing.
- Provide planning and tools to enable joint DMS problem recognition and problem solving opportunities.
- Establishing mechanisms to combine military and commercial efforts to improve low volume procurements.

- Establishing common guidelines for DMS substitution.

- Verifying military requirements to insure operating systems are not over-specified, enabling commercial alternatives.

- Adopting commercial procurement and maintenance practices, including using multi-year contracting and life-time product support agreements, 2-level maintenance and incorporating maintenance incentives.

Commercial practices provide many opportunities for military DMS managers. Unfortunately, Tanemura's briefing did not contain cost comparisons.

DMS Case Studies

F-15 Radar Upgrade

The government and industry effectively combined several coping strategies to offset DMS concerns with the F-15 Eagle's key APG-63 tracking radar. Manufactured by Hughes (now Raytheon), the APG-63 is a lightweight, highly digitized X-band pulse doppler radar with numerous ICs. Now over 30 years old, the APG-63 faced DMS-derived obsolescence a long time ago. In the mid 1990's the SPO at Warner-Robins Air Logistics Center, Georgia and the key contractors, McDonnell-Douglas (now Boeing) and Hughes embarked on a versatile campaign plan to upgrade the radar and maintain the F-15s superiority as an air-to-air weapon system.

Initially, the government-industry team conducted a thorough cost analysis, weighing the merits of designing/building a replacement system versus upgrading the current APG-63. Hughes sponsored multiple manufacturers to design radar component prototypes in a successful effort to identify less expensive options.[25] Next, using a building block approach, they decided to proceed with the best of both options; replace the old radar with a new system, the APG-63V(l), but fight obsolescence with interim component upgrades that will also be used in the final replacement radar. By employing component *simulation* and *emulation,* within an *open architecture* and parts *life of type* contract, this counter-DMS team replaced some common components, designed semiconductor substrate patterns on existing ICs (aka "hybrid microelectronic circuit") for other components, and instilled a rigorous upgrade/replacement schedule for *all* components during the development period for the APG-63V(l) (approximately five years). The result of this savvy use of *multiple* DMS strategies for the APG-63 radar was transparency: the F-15 Eagle's performance never skipped a beat despite the dilemma of "old" technology, and equally impressive, the "virtual elimination" [26] of obsolescence within the radar itself was achieved at a "fraction of the cost" of the replacement system.[27]

We could not capture the costs to manage the APG-63V(l) design upgrades or the expected program savings. The F-15 Avionics DMS focal point at WR-ALC said that since the APG 63V(1) has a 2 level maintenance concept with the contractor serving as the depot, these costs were not readily available. However, the DMS program costs for all F-15 avionics, including the APG 63 and the APG 70 (the F-15E radar), are shown on attachment 2. These radars have a 3 level maintenance program and WR-ALC is the depot. As the attachment shows, since the early 1990s through 2002, F-15 avionics DMS

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[25] Warner-Robins Air Logistics Center, "Diminishing Manufacturing Sources and Material Shortages: Secrets of the Solution," http://www.ball.com/aerospace/wrdms5.html
[26] Warner-Robins Air Logistics Center, "Diminishing Manufacturing Sources and Material Shortages: Success Story," http://www.ball.com/aerospace/wrdms4.html
[27] Ibid

costs were $11M and the cost avoidance was $134.2M. The majority of these cost and savings are attributed to the APG 63 and 70 radars.

Point of Contact: Mr. Sam Calloway, F-15 Avionics DMS Program Manager (478-926-3594)

The F/A-22 DMS Program

The F/A-22 SPO at Wright-Patterson AFB, OH contracted with Lockheed Martin (LM) in Marietta, GA for "Transparent Management" of the DMS program. This means that the SPO gave LM the authority to make decisions regarding managing and resolving DMS issues. LM uses web-based management systems to manage and communicate status and issues. LM levies a contractual requirement to all its major suppliers to identify in advance any components that will no longer be manufactured. This requirement consists of a complete set of instructions for reporting issues and the process for developing alternate sources, proposing buy-outs, and developing alternate designs.

Once the supplier has identified a DMS problem to the LM DMS program manager, the supplier will work with the appropriate LM and SPO Integrated Product Team (IPT) to prepare and present a trade study to decide the appropriate course of action. The goal is to provide timely identification allowing production of new components one-year before the obsolete parts run out. DMS components with at least one year overlap are rated satisfactory or green, those with less than one year are rated moderate risk or yellow, and finally those without any overlap, i.e., those projected to cause a gap in production are rated high risk or red.

If the trade study calls for a product redesign, special "DMS resistant" design criteria is levied to minimize future exposure to DMS. For example, LM has found that electronic components have an average life-cycle of 5 years and some semi-conductors have a 2-3 year "wear-out" life span. Some semi-conductor materials literally shrink and wear out during use and must be replaced. During the component's Preliminary Design Review, LM will insure the supplier's new design utilizes technologies on the front end of their 5 year life-cycle to maximize the duration before obsolescence. In addition, LM encourages its suppliers to select electronic components from manufacturers whose components are "backward compatible" and use semi-conductors that minimize die shrinkage in an effort to become DMS resistant. LM has compiled and made available for its suppliers a DMS design database containing best practices.

Over 60 F/A-22 major suppliers are involved in the program today, with plans to reach more suppliers in the future. LM manages a web-site containing the status of all DMS issues, with ready access by the SPO and limited access by the suppliers. The DMS program has recently been negotiated for Lot 3 (Calendar Year 2003) and has averaged around $100M/year total, with $40M allocated for unknown issues and $60M+ for managing current known issues. The DMS program was initiated during the middle of the F/A-22's Engineering and Manufacturing Development (EMD) phase after the June 1994 William Perry memo instructing the services to adopt commercial products and standards in order to reduce costs. LM has 2 full-time managers in Marietta, part time support from Lockheed-Ft. Worth and 1 person in Boeing-Seattle. These people manage the overall DMS program while individual DMS, issues are managed by the affected IPTs.

Upcoming Activities:

- LM will be releasing its new F/A-22 DMS procedures document in a couple months.
- The, next DMS conference sponsored by DMEA will be in San Diego from 18-21 August 2003. The following web-site has details: www.dmsms2003.utcdayton.com

Points of Contacts:

- LM's F/A-22 DMS program manager is George Sacarelos (770-793-0816 or george.a.sacarelos@lmco.com)
- The F/A-22 DMS program manager is Jason Cornelli, ASC/YFAA (937-904-5154 or Jason.cornelli@wpafb.af.mil)

Joint Strike Fighter (JSF) DMS Program

The JSF (F-35) DMS program is a subset of its overall Technical Refreshment Program (TRP) which is described in its comprehensive TRP Plan. The TRP seeks to achieve weapon system affordability/supportability and to minimize DMS risks through proactive DMS management measures, using commercial approaches and standards, and incentivizing contractors to achieve program goals.

The JSF program is currently entering the Preliminary Design Review stage and therefore hasn't experienced any significant DMS issues, yet. The JSF DMS program is similar to the F/A-22 DMS program in many respects. The JSF SPO in Crystal City (Arlington), VA has delegated responsibility to the prime contractor, which manages the program with its suppliers. Lockheed Martin, Ft. Worth, TX (LM) is populating its databases with electronic bills of materials, supplier action-plans and forecasts, and will be interfacing with the Lockheed corporate DMS data bases. LM has a relatively brief statement of work defining its responsibility and activity it provided for the SPO; however, they have levied detailed and very specific instructions to its major suppliers.

LM delegates even more responsibility to their JSF suppliers than LM has on the F/A-22 program. Similar to the commercial aerospace industry, the JSF suppliers are responsible for ensuring product supportability, reliability, affordability and availability throughout the operational life of the JSF. While all major suppliers are included, the primary focus is on the micro-electronic suppliers whose product technologies change frequently. The suppliers follow proactive design measures to minimize DMS impacts and in the case of a DMS issue, have full authority to make changes that do not affect the form, fit, function, or interface (F31) characteristics. Since the suppliers are incentivized to insure part supportability and affordability, they will continuously seek opportunities to introduce new technologies to achieve these goals.

The suppliers are required to notify LM within 2 years of effectivity, if a DMS, or an affordability opportunity will result in a design change that affects F31. Additionally, the suppliers are required to submit an action plan describing the proposed solution and to update these plans every six months. Issues and plans are brought to the attention of the product IPTs who will be responsible for working with the suppliers to reach a decision on the proper course of action. The Tech Refresh/DMS team operate at the Air System level overseeing all the air vehicle, autonomic logistics, and training systems IPTs.

Michael Mullins, the LM leader of the DMS Tech Refresh Team, indicated that funding DMS & Tech Refresh related activities in subsequent lots is his greatest concern. In some DMS cases, suppliers should place orders and buy new parts for future lots. However, since the Government provides annual year funding, these orders will be disrupted, thereby impacting potential cost savings, supportability, and increasing schedule risks. Since the program is still early in development, he hopes to find ways to resolve this issue. In addition, Mullns is working with the Navy's Supply-Chain Practices for Affordable Navy Systems (SPANS) program (www.spans.org) to strengthen the supply-chain through technology projects, and maintains contact with DMEA to keep abreast of DMS best practices.

The LM-Northup Grumman-BAE Tech Refresh Team is comprised of 7 people who are primarily working planning and administrative issues at this time. Therefore, the Tech Refresh and DMS costs are currently very limited.

Points of Contact:

- LMCO DMS focal point: Michael Mullins, Lockheed Supplier Management (Tel: 817-763-4988 or michael.p.mullins@lmco.com).
- JSF DMS focal point: LtCol Jim Geurts, USAF F-35 Mission Systems IPT Lead

AEGIS DMS Program

Another good example of DMS management involves the Navy's Surface Warfare PM's relationship with industry for acquisition and upgrades of the AEGIS cruisers and destroyers. By almost completely charging the prime contractor, Lockheed Martin-Eagan (LM), with the task of combating obsolescence, NAVSEA PMs continue to keep near state-of-the-art ships afloat.

LM's DMS-coping strategy begins with the development of a technology roadmap that emphasizes true system requirements vs. rigid adherence to military specifications. The LM PM forms an industry version of an IPT (called "COTS Working

Group", or CWG) with subcontractors and suppliers that lasts for the life of the contract (usually 5-7 years, although AEGIS contracts run concurrently for 15-20 years). The CWG is tasked to continually monitor technological advances; on average for systems like the new AEGIS DDG-103, for example, the team keeps track of over 2000 microelectronic parts. Since the technology roadmap stresses capabilities over specifications, the CWG jointly searches for suitable microelectronic substitutes to the obsolescent component. Upon finding a replacement component that is "backwards compatible" with other components (thus ensuring system integration), LM will meet with the Navy to determine the type of contract (life of type or interim purchase); the key to the CWG's success is determining the replacement solution well before the component is obsolete. An added cost benefit is the elimination of mandatory "regression testing" for agreed-to interim replacement components. Best suited for processors and other hardware, this anomaly to traditional system development is made possible by the Navy's trust in LM's requirements vs specifications approach. As expected, the Navy's Surface PMs are pleased with LM's performance, and their confidence was further justified by a Booz-Allen contracted review which cited the Eagan, Minnesota company for "world class COTS integration." More importantly, according to the Navy's PM, LM's strategy to refresh obsolete technology saves over $4 million for major AEGIS components. [28]

Points of Contact:

- Lockheed Martin-Eagan AEGIS Program Manager: Steve Froelich, (651-456-2315)
- Navy Surface DMS Program Manager: Evangelos Karagiorgis, (202-781-1346)

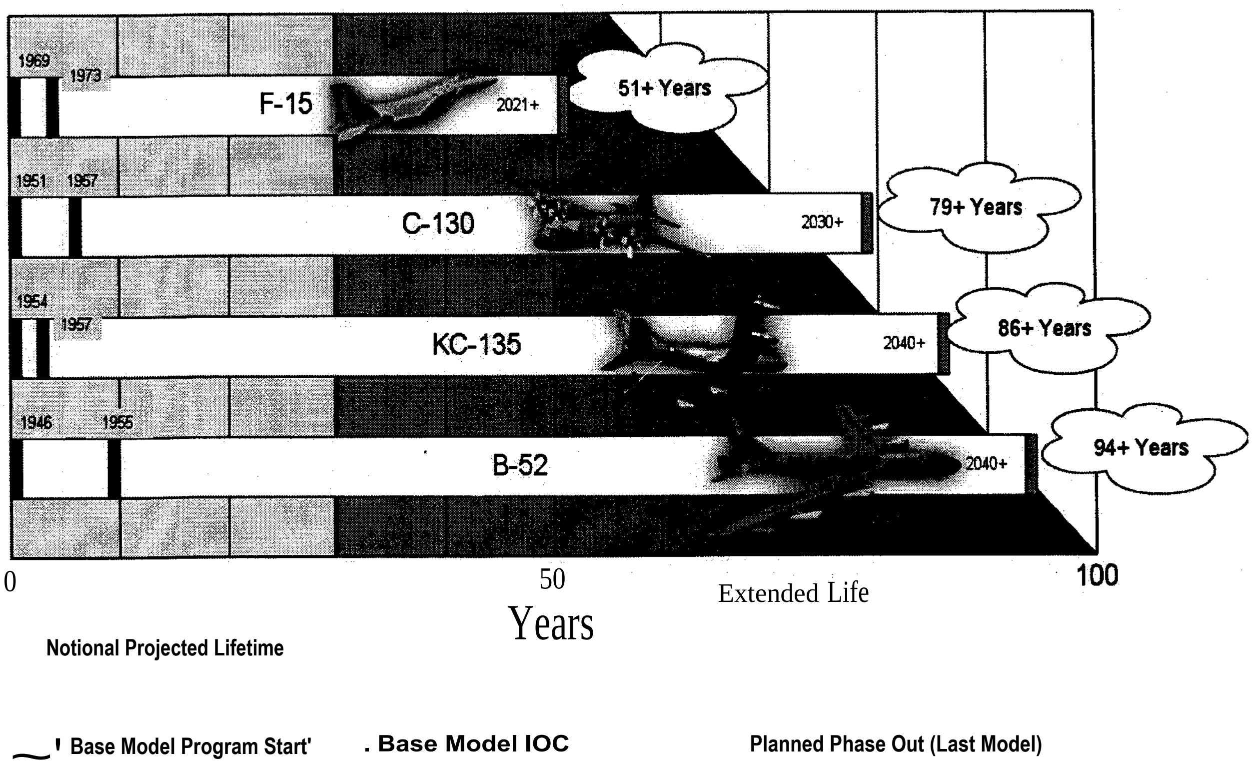
[28] Evangelos Karagiorgis, U.S. Navy Surface program manager, e-mail, March 27, 2003

Conclusion

In the best of times, the Microelectronics aspects of Department of Defense weapons systems development is a challenging business. Ever-changing requirements caused by ever-changing threats, extremely complex systems comprised of hundreds of hardware and software component parts, and inconsistent program funding lines all conspire to make life difficult for government and industry program managers. Add in the phenomena of Moore's Law, and it's a wonder that supportable weapons are ever fielded at all. Fortunately, there are proactive managers across DoD and industry who successfully combat the law and its DMS offspring. While Moore's Law will most likely run its course by 2010 due to physical and fiscal limitations, microchip innovations will certainly continue. Therefore, recent DoD and prime contractor strategies to force system supportability requirements onto suppliers and subcontractors represent management initiatives that must also continue. JSF, F/A-22, F-15, and Aegis PMs have all implemented elements of a thoughtful and well-organized Government Electronics Industry Association primer on DMS management, and in doing so, saved millions of taxpayer dollars. We recommend all DoD PMs become knowledgeable of DMS and employ the best DMS practices to win the war against obsolescence.

Attachment 1

Extended Systems Lif



DMSMS Is Driven by Technology Turnover *and* the Marketplace; Highest in Electronics, but

N Matter the Commo Group. DMSMS Limits Operational Readiness

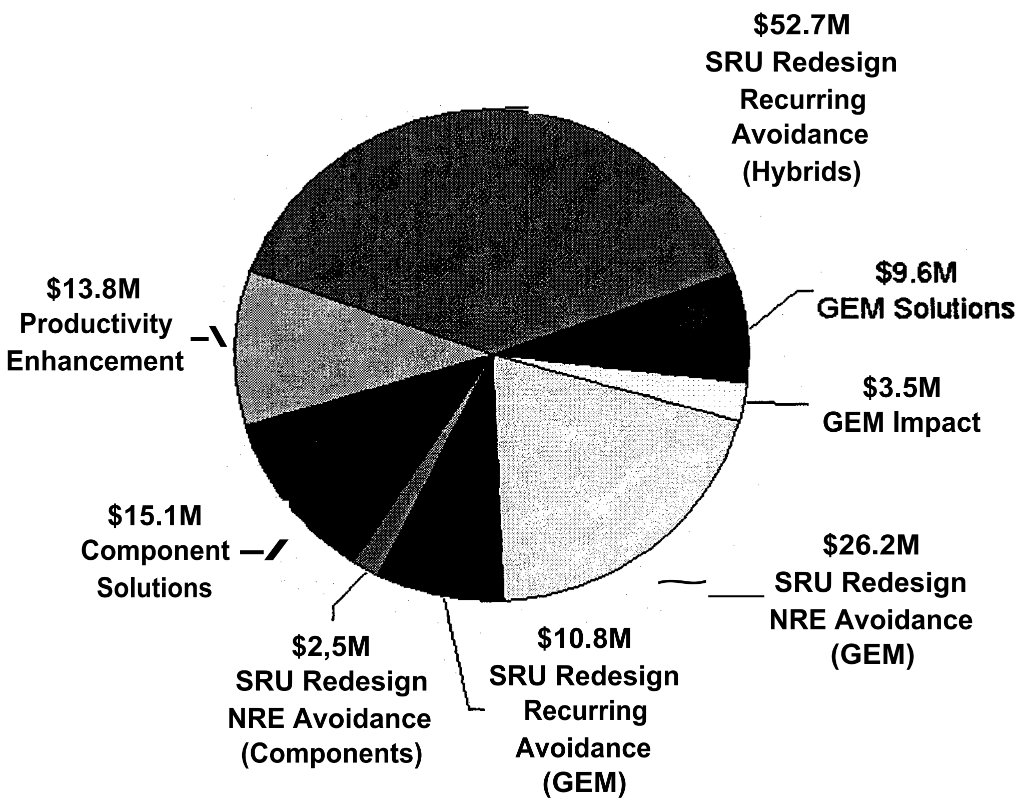
AFMC's SYS 400 DMSMS Program Briefing, by James Neeley, AFRL/MLT
James.Neely@wpafb.af mil (937-904-4374)

Attachment 2

F-15 Avionics Program

F- nvestment since car
1990s: S I NXI

Cum Cost Avoidance through



GEM= Generalized Emulation of Microcircuits

AFMC's SYS 400 DMSMS Program Briefing, by James Neeley, AFRL/MLT
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