Chapter Four

COMMERCIAL INSERTION AND THE QUESTION OF WEAPON SYSTEM PERFORMANCE

INTRODUCTION

As noted in earlier chapters, many CMI advocates argue that market-driven commercial R&D has surpassed military R&D in diverse technology areas. The implication is that the broader use of commercially developed technologies in the military sector would result in more-capable weapon systems. Yet paradoxically, perhaps the single most important and deeply felt concern expressed by CMI skeptics is that the military use of commercial parts, components, designs, and technologies will result in less-capable and less-reliable weapon systems. These concerns arise from a belief that weapon systems often must be able to operate in far more stressful and demanding environments than commercial products. This is a crucial issue, because CMI must be viewed as an unacceptable strategy if it results in less-capable or less-reliable weapon systems than are needed by America's armed forces.

This chapter attempts to shed additional light on the debate over dual-use performance by examining evidence from our case studies of various aspects of CMI applied to RF/microwave military technology programs to answer our second question:

- Is the commercial market driving technology at a rate and in a direction that meets national security requirements? In other words, can CMI provide the necessary and desired military equipment performance capabilities?

We first examine the question of "insertion" of commercially developed parts and components into radars and other RF/microwave military systems. We then briefly examine the use of commercially derived technologies and designs in similar systems.[1]

INSERTION OF COMMERCIAL PARTS AND COMPONENTS

Parts insertion refers to the use of standard "off-the-shelf" (OTS) commercial electrical components and parts such as integrated circuits in weapon systems. Prior to June 1994, almost all parts used in military systems were required to adhere to official Mil-Specs. Mil-Specs were originally developed in the 1960s to ensure that parts used in military systems would possess the necessary robustness and capabilities to operate in harsh military environments, and to ensure reliability, quality, configuration control, and logistics support.[2] By the early 1990s, approximately 40,000 Mil-Specs provided uniform technical and management standards for the design and development of weapon systems and other military applications. Technical Mil-Specs can be very precise and detailed, often specifying materials, processes, design standards, and so forth down to the lowest parts level.

As noted in Chapter Two, acquisition reformers argue that Mil-Specs are a major barrier to CMI, because commercial parts and components are usually designed and developed in accordance with different technical standards. As a consequence, Mil-Specs often require the use of unique parts specially developed for military applications. Such parts are produced in small quantities and must be subjected to extensive test and screening procedures, and thus are very expensive. Yet acquisition reformers contend that Mil-Specs are often outdated, sometimes mandate the use of unnecessary capabilities and technologies, and may lead to the use of less-capable but more-expensive technology than is available in the commercial sector.

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[1]DoD has defined "insertion of commercial capabilities into military systems" as the "Third Pillar" of its three-pillar dual-use CMI strategy. According to DoD, insertion entails the use of "best commercial materials, products, components, processes, practices, and technologies into military systems whenever possible." See OUSD/A&T (February 1995).

[2]This discussion of Mil-Specs is drawn largely from OUSD/A&T (October 1996), Appendix A.

Nonetheless, serious concerns remain in the services and in the defense industry regarding the advisability of eliminating Mil-Specs and routinely using OTS commercial parts in military systems.[3] These concerns arise from the view that the military environment is far harsher and more demanding than the relatively benign environments in which most commercial parts are designed to operate. The most serious concerns focus on the capabilities of commercial parts to withstand the harsh extremes of temperature, vibration, altitude, g-forces, and humidity required by Mil-Specs. Observers also have raised questions about cycle and long-term shelf life.

As a result of these concerns, DoD and the services have concluded that initial Mil-Spec reform implementation was "frequently overzealous," and that greater caution and care must be taken in eliminating Mil-Specs. Studies have been undertaken to determine more precisely where the continued requirement for Mil-Spec parts might be warranted.[4] These studies have contributed to a growing body of evidence that, if implemented with care, insertion of a wide spectrum of selected commercial parts in RF/microwave military systems and other military electronics can be a viable strategy.

In 1996, the Electronic Industries Association (EIA) surveyed eight major military electronics contractors to determine the use of commercial parts in military systems.[5] Seven of the eight participating firms had experience with applying commercial parts to military systems, including radars, missiles, and communications systems.[6] The principal conclusion of the study was that commercial parts can be incorporated in military systems without significantly degrading system performance.

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[3]For a thorough and thoughtful review of concerns in the defense electronics industry, see EIA (January 1997).

[4]See, for example, OUSD/A&T (October 1996).

[5]The eight participants were Allied Signal, David Sarnoff Research Center, GEC-Marconi Electronic Systems, GTE, Lockheed Martin, Northrop Grumman, Rockwell International, and Texas Instruments.

[6]Applications included MODAR, APS-134(LW), APS-137(V), F-16, Joint Tactical Information Distribution System and Multifunctional Information Distribution System, Longbow missile, Tomahawk, Javelin Command Launch Unit, Wind Corrected Munitions Dispenser, and the Tri-Band Tactical Terminal.

However, a major caveat accompanying this conclusion was that the data supporting it are still "limited." The single greatest concern of the respondents was the difficulties they were experiencing in finding adequate characterization data on commercial parts so that they could be used with confidence as substitutes for Mil-Spec parts. There is a lack of information about the long-term reliability of commercial parts when used in stressful military operating environments. In other words, a commercial off-the-shelf (COTS) or custom part might substitute for a Mil-Spec part perfectly well in performance characteristics, but might not—it was feared—possess the robustness to provide the required reliability in harsh military environments. The key technical issues were:

- Temperature operating ranges
- Tolerance to moisture
- Tolerance to vibration
- Tolerance to high-altitude environments
- Tolerance to high g-forces
- Cycle life
- "Footprint" incompatibilities.[7]

A wide range of grades of COTS and custom parts that are not Mil-Spec are available on the market.[8] These grades represent a spectrum of parts with different temperature, moisture, and vibration ranges that are available in the commercial world. The most com-

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[7]The footprint of an electrical part refers to its size, number of pins, pin arrangement, and so forth.

[8]Industry parts specialists argue that, strictly defined, all parts that are available from standard catalogs, including Mil-Spec parts, are COTS parts. Standard Mil-Spec catalog parts are sometimes called Government Off-the-Shelf (GOTS). Custom parts are COTS or GOTS parts that require additional screening, testing, or selection beyond the catalog definition. Custom-designed parts, whether used in military or commercial applications, are not considered COTS parts. Many military radars use nonstandard or custom-designed parts that must receive government approval. These parts technically are not Mil-Spec but rather government-approved nonstandard parts. Some industry experts argue that the use of Mil-Spec GOTS parts is often cheaper than using non–Mil-Spec COTS parts, because of the high costs of screening the latter parts for insertion into military systems. See Martin (1995).

mon grades of commercial electronics parts are called "consumer grade," "industrial," or "automotive grade," as shown in Table 4.1. Thus, industrial-grade parts, which are used in automobiles and trucks, have much wider recommended temperature operating ranges than do consumer-grade parts, which are meant for consumer electronics such as televisions and VCRs. Also, screening (testing beyond catalog definition of recommended performance environment ranges) is often available for industrial parts, although usually not for consumer parts. Indeed, most major car manufacturers have close relationships with their electronics parts vendors and set various rigorous standards for operating environments, which may require screening. In a variety of demanding commercial applications, such as engine-control integrated circuits for heavy construction equipment, for example, parts may be screened to operate in temperature, vibration, heat, and moisture environments that exceed those typical of Mil-Spec parts. With regard to footprint, commercial parts are often incompatible with Mil-Spec parts because the rapidly advancing commercial market has pushed the parts technology beyond the Mil-Spec world.[9] If military electronics modules are designed for commercial parts insertion from inception, footprint is usually not a problem.[10]

Table 4.1

Examples of Differences Between Various Grades of Parts

Characteristic	Mil-Spec Grade	Consumer Grade	Industrial/ Automotive Grade
Temperature range	–55°C to +125°C	0°C to +70°C	–40°C/–25°C to +85°C
Packaging/ encapsulation	Ceramic or metal	Plastic	Plastic or hermetic
Screening	Yes	Usually none	Usually none, but available
Footprint	Mil-Spec baseline	Usually incompatible	Usually incompatible

[9]Some differences also arise from encapsulation in plastics vs. ceramics or metals.

[10]Severe space and weight constraints in densely packed fighter aircraft sometimes require specialized parts, packaging, and cooling.

Our case study evidence suggests that the real-world experiences in system performance of contractors committed to commercial parts insertion have been mostly positive. A key characteristic of successful efforts appears to be contractor configuration control; that is, granting the contractor the freedom (and responsibility) to select the most cost-effective and appropriate grade for every part in an avionics module, assembly, or system.

Mil-Specs tend to be extremely conservative and sometimes grossly overspecify performance-range requirements for parts. Engineers who are actually designing and developing a specific module often have a far better understanding of what performance requirements are necessary for each part and component in that module. Mil-Specs can limit or constrain cost-effective solutions by overspecifying requirements or mandating the use of outdated or inappropriate technologies. And there is a direct correlation between parts grades and cost, as illustrated in Figure 4.1. Sometimes an industrial-grade or even a consumer-grade part may be perfectly adequate for a given

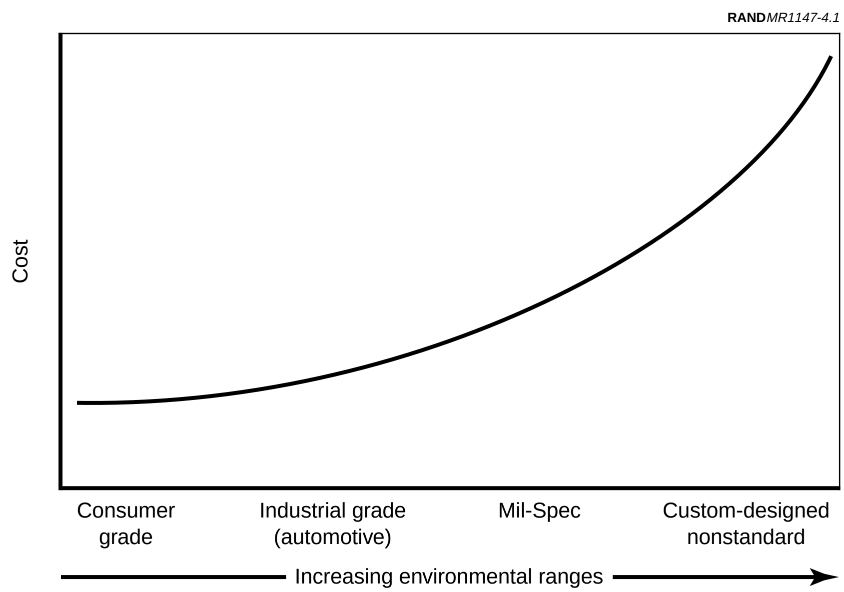

Figure 4.1—Greater Temperature, Moisture, and Vibration Ranges Increase Parts' Costs

application and may adequately support the overall performance capabilities requirements of the module. At other times, no commercially available part exists—or none that has the necessary environmental performance range characteristics—for a specific military application, particularly in the RF/microwave world. In such cases, Mil-Spec or other types of nonstandard or custom parts should of course be used.

The limited experience of contractors suggests that a carefully selected mix of Mil-Spec, industrial-grade, and consumer-grade parts can be used with little or no degradation in performance and high payoffs in lower costs, provided the contractor is granted configuration control and change authority. An interesting recent experiment in this area is the Manufacturing Technology Industrial Base Pilot Program (Mantech IBP) for producing military products on commercial production lines.[11] Sponsored by the U.S. Air Force Manufacturing Technology Directorate at Wright Laboratory, the Mantech IBP program demonstrates the design and manufacture of complex military avionics components in accordance with best commercial practices. TRW Avionics Systems Division has been contracted to produce two electronics modules from the CNI for the F-22 fighter and the U.S. Army's Comanche RAH-66 reconnaissance/attack helicopter. These modules will be manufactured by TRW's Automotive Engineering Group at a standard, fully automated commercial automotive electronics plant in Marshall, Illinois.

A key objective of the program is to maximize compatibility with normal automotive production-line processes and minimize disruption to ongoing commercial programs. To achieve this objective, the military modules had to exhibit maximum parts and design commonality with the commercial automotive items produced at the factory such as electronic engine controls and air bag sensors. At the same time, the modules had to possess equivalent performance capabilities and cost less than modules manufactured on military lines, and had to be fully compatible with the other modules in the F-22 and RAH-66 CNI. These objectives had to be achieved without electrical redesign of the modules. To achieve compatibility with auto-

[11]For an overview of this program, see U.S. GAO (June 1996).

motive electronic manufacturing processes, Mil-Spec parts had to be replaced with commercial automotive-grade parts.[12]

Engineers selected two typical digital CNI modules—out of a total of 38 modules that make up the complete CNI system—for the pilot program: The RF/front-end controller and the pulse narrowband processor. These modules were reconfigured so that they contained about 90 percent commercial parts and components. The redesigned modules used the advanced plastic packaging approaches and recently developed ball grid-array technology for ASICs and multichip modules that are used in cutting-edge commercial applications, but that are virtually non-existent in military electronics.

Initial testing indicates that the performance, reliability, and cycle life of these modules equals or exceeds similar modules built with full Mil-Spec parts and components and manufactured on Mil-Spec military production lines. As of mid 1996, initial testing showed that the functionality and durability life of the two IBP test modules equaled the baseline performance established for the Mil-Spec modules. Plastic encapsulated microcircuits passed all tests. Test results also showed that large ball grid arrays used in the modules could endure stressful thermal cycling. Furthermore the IBP test modules weighed about 15 percent less than the baseline target weight for the Mil-Spec modules.[13]

We identified two other interesting cases of commercial parts insertion: The AIL Systems family of modular radars derived in part from the AN/TPS-74 Modular Radar (MODAR) developed for the U.S. Army in the late 1980s, and the Northrop Grumman ESSD/GEC-Marconi Systems Programmable Digital Radio (PDR) for CNI applications.

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[12]As noted earlier, the different footprints of Mil-Spec parts often make them incompatible with standard commercial automated manufacturing equipment.

[13]TRW engineers argue that plastic encapsulated microcircuits are suitable for most military applications. See Myers and Bartlett (1996). An alternative view can be found in Donlin (February 1995). Donlin raises concerns over the lack of data on the reliability of plastic encapsulated microcircuits when used in systems such as missiles that are stored in a dormant state for years in harsh environments or subjected to high humidity levels.

AIL is developing and producing a limited production run of radar common modules, including antennas, receiver/exciters, power amplifiers, pedestals, and signal processors. The company is targeting a wide range of potential U.S. and foreign military and commercial customers, so the modularity of the design is critical. The modules can be mixed and matched to produce radar systems appropriate for a wide range of military and civilian ground and airborne applications.[14] AIL originally intended to procure all full-Mil-Spec-grade parts. However, cost and schedule considerations led AIL to consider industrial/automotive- and consumer-grade parts. For many components, AIL engineers concluded that the use of non–Mil-Spec parts would provide equal or better performance capabilities at a lower cost with a shorter development time.[15] The resulting radar modules are a mix of Mil-Spec, industrial-grade, and consumer-grade parts.

Because of continuing uncertainties regarding the reliability of non–Mil-Spec parts in harsh military environments, AIL recognized the importance of implementing a thorough test program of its modules. Engineers are paying special attention to rigorous temperature and vibration testing of the modules. Typical are the results obtained with the signal processor, which contains all three grades of parts, and the pedestal, which contains all industrial-grade parts. No vibration problems were encountered with either module during testing. The same was true when the modules were tested at temperatures well above the recommended ranges for industrial- and commercial-grade parts. However, serious performance degradation problems were encountered at temperatures below –30°C. For effective operation in environments below –30°C, the modules will have to be protected or different parts will have to be used.

Northrop Grumman ESSD and GEC-Marconi are developing a flexible PDR based on a similar modular concept, for use in a variety of applications, including CNI upgrades for export versions of the Boeing/McDonnell F-15. The PDR will eventually incorporate a va-

[14] Existing versions include a Ku-band ground-based moving target indicator battlefield surveillance radar (AN/TPS-74) and Ku-band Remotely Piloted Vehicle/ Unmanned Aerial Vehicle (UAV) modular radar.

[15] In general industrial- and consumer-grade parts can be obtained much more quickly from suppliers than can Mil-Spec parts. See Chapter Five.

riety of microwave functions, including Ku/Ka-band satellite communications and microwave landing systems.[16] Similar to the AIL MODAR, the PDR uses non–Mil-Spec parts whenever possible to keep costs down and shorten the R&D cycle. When Mil-Spec parts were deemed necessary, GOTS components were selected. For example, the system uses an autonomous target-recognition chassis and card set from a proven militarized radar product, combined with industrial- and consumer-grade parts such as COTS television filters and field-programmable gate arrays. Overall the developers applied normal commercial ISO 9000 standards rather than Mil-Spec standards. The PDR prototypes have been successfully tested in simulated operational environments such as at the 1995 Joint Warrior Interoperability Demonstration in San Diego.

Other experiments are under way by a wide variety of contractors working with all three services to examine the insertion of non–Mil-Spec parts into military systems and subsystems. Our examination of several case studies in the demanding RF/microwave technology area provides additional encouraging—though still limited and qualified—evidence that a carefully framed CMI strategy on the parts level can lead to systems exhibiting equal or better performance capabilities compared with systems developed entirely with Mil-Spec parts.

Several caveats are necessary, however. There still are not analogous parts and components available on the non–Mil-Spec commercial market necessary for certain microwave applications used for advanced military radars. Yet, as discussed earlier, civilian applications are now increasingly driving RF/microwave and MMW technologies, leading to the commercial development of more and more parts and technologies relevant to military microwave applications. Defense contractors interested in CMI have adopted a strategy of inserting a mix of custom Mil-Spec, industrial-grade, and consumer-grade parts into RF/microwave subsystems. The specific mix is determined by tradeoff analyses of a variety of factors such as overall system performance, cost, and schedule requirements.

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[16]The baseline prototype design is 1.5 MHz to 2.8 GHz.

Even with the current approach of using a mix of different grades of parts, concerns remain widespread in industry regarding the long-term reliability and durability of such hybrid systems. The test evidence is mostly encouraging, but it remains limited. Hybrid systems will have to continue to be tested extensively for their long-term resistance to extremes of temperature, humidity, vibration, and other environmental factors before they can be used with complete confidence in stressful military environments.

INSERTION OF COMMERCIALLY DERIVED DESIGN APPROACHES, TECHNOLOGIES, AND PROCESSES

The simplest form of CMI entails insertion of non-Mil-Spec COTS parts and components into military systems. A more comprehensive CMI strategy would involve "spinning-on" or more effectively exploiting commercially derived design approaches, technologies, and processes for military applications. Such a strategy would not necessarily require the use of COTS parts, although such an approach would be encouraged. Rather, developers of military systems would attempt to take greater advantage of relevant design approaches and technologies available or under development in the commercial marketplace. CMI advocates claim that such an approach will improve system performance through the incorporation of more-advanced commercial technologies and processes into weapon systems, reduce R&D costs by piggybacking on commercial R&D expenditures, and help maintain a dual-use industrial base at lower cost to the government. Several of the case studies we examined provided encouraging, though limited, evidence supporting this claim of the CMI advocates.

DARPA has been particularly active in sponsoring projects that promote dual-use technology development in microwave technologies and other areas. One project of direct relevance to our study is the Technology Reinvestment Project (TRP) on RF/Microwave/MMW technologies, supervised by the U.S. Air Force Wright Laboratory.[17]

[17]The official program title is "Development and Application of Advanced Dual-Use Microwave Technologies for Wireless Communications and Sensors for IVHS Vehicles," but the scope of the effort has been broadened considerably since this title was formulated. The participants are Northrop Grumman Electronic Systems, M/A-

A goal of this program is to help defense contractors leverage their skills and capabilities in military microwave technologies to enter commercial markets in related areas, to promote the "spin-back" of more advanced commercial technologies to defense applications.

Northrop Grumman Electronic Systems in Rolling Meadows, Illinois, is a major participant in the DARPA/TRP programs. This company is the developer and manufacturer of the ALQ-135 electronic warfare system deployed on the Boeing/McDonnell F-15E, and is involved in a variety of other EW programs that draw heavily on microwave and MMW technologies. Under the auspices of the DARPA TRP program launched in 1994, Northrop began to develop a variety of commercial "spin-off" applications of its microwave technologies in automotive radar sensors and wireless communications. After two years, Northrop had developed a variety of systems and components, including a 24-GHz Wireless Link GaAs MMIC transceiver module, 900- and 1800-MGz MMIC-based wireless modems, a 24-GHz automotive radar sensor, radio-frequency identification systems, and a wideband 2–6-GHz Microwave Power Module (MPM), and had begun development of an 18–40-GHz MPM (Northrop Grumman, July 1996).[18]

Development of these commercial applications had an immediate and dramatic effect on the contractor's military product development plans. The development of advanced solid-state wideband MPMs for commercial use is of particular interest for military microwave applications. The most technologically advanced EW systems deployed on U.S. Air Force fighters still use large, extremely expensive, low-reliability traveling wave tube technology. For microwave transmitter applications, the commercial world has moved toward much more reliable, cheaper, lighter-weight MPMs for high-power amplifiers.

TRP program experience developing commercial technologies has led to new proposals for incorporation of advanced MPM technology into EW and other military system applications. As mentioned ear-

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COM, Wright Laboratory, University of Illinois, Northwest University, and several smaller private companies.

[18]Related technology developments came out of the DARPA-sponsored Microwave and Millimeter-Wave Integrated Circuit (MIMIC) and Microwave and Analog Front-End Technology (MAFET) programs .

lier, ball grid-array integrated circuit packaging technology has been driven by commercial developments, but is virtually non-existent in Mil-Spec electronics applications. The TRP program led participants to develop and employ ball grid-array technology for commercial wireless applications, then make it available for military applications. The same is true of many other advanced commercial microwave technologies, such as direct-sequence spread-spectrum devices with ASIC/MMIC, various forms of plastic packaging, and many process technologies.

CONCLUSION

Our findings on the performance consequences of commercial technology insertion into military avionics, based on analysis of our case studies, can be summed up as follows:

- Limited evidence suggests that commercial-grade parts and components can be successfully inserted into RF/microwave military avionics systems without degrading system performance. However, many Mil-Spec, specially screened commercial parts, or custom-designed parts and components are still likely to be necessary. Furthermore, legitimate concerns remain about the long-term reliability and durability of commercial-grade parts. These concerns can be addressed through further testing and experimentation.
- Limited evidence suggests that commercially derived designs, technologies, and processes can be successfully applied to military RF/microwave systems with the potential of increasing performance. Many of the design approaches and technologies in the commercial sector appear to be far more advanced than what is currently available in the military sector.
- Granting full configuration control and change authority to the contractor appears to promote the successful insertion of commercial parts and technologies into military RF/microwave systems.