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The Joint Tactical Radio System: Lessons Learned and the Way Forward

By:
Jacques S. Gansler, William Lucyshyn, and John Rigilano

Center for Public Policy and Private Enterprise
School of Public Policy

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Table of Contents

List of Figures

Executive Summary

In 1997 the Department of Defense (DoD) launched the Joint Tactical Radio System (JTRS; pronounced "jitters"), a transformational communications network that will permit warfighters and support personnel to seamlessly transmit voice, picture, and video via a high-capacity wireless network. Since the program's inception, however, DoD officials have consistently overestimated the ease with which various components of JTRS could be developed and implemented. This has resulted in a program that has experienced delays, unforeseen technical hurdles, and major cost overruns.

JTRS is a software-defined radio (SDR), although it is more like a computer than a traditional radio. Functions that are traditionally built into a radio's hardware are, instead, implemented through software. As a result, with the proper software, JTRS can emulate a variety of different physical radios, but also has the ability to download data and imagery. An open systems framework known as the Software Communications Architecture (SCA) is key to the system's interoperability; it "tells designers how elements of hardware and software are to operate in harmony" (Brown, Sticklan, & Babich, 2005, p. 1) thus enabling users of different JTRS variants (airborne, maritime, ground, fixed, etc.) to load and run the same software applications.

Initially, a Joint Program Office (JPO) was established and tasked with development of the SCA; development of the JTRS radios themselves was divided into five clusters, each of which was headed by one of the military services. For instance, the Air Force was tasked with developing JTRS for Air Force and Navy fixed-wing aircraft and helicopters, while the Army oversaw development of handheld, man-portable, and other small JTRS variants. The perceived simplicity behind the open architecture concept guided DoD officials in establishing this initial, decentralized management structure and acquisition strategy.

The rationale behind the service-led clusters approach relied upon a number of assumptions: (1) A universal, open architecture would provide a solid foundation on which to develop and produce interoperable JTRS variants and that (2) other technologies needed to create the end

products were ancillary, easily acquired, and adaptable. In other words, the DoD expected the SCA "to provide the services with sufficiently developed hardware and software prototypes that they [could] use to immediately procure JTRS products" (General Accounting Office [GAO], 1999, p. 8). However, the JTRS program's failure to define the specific limitations of the available technology, and, instead, rely heavily on the SCA—a"responsive" and "flexible" architecture—led to the belief that difficult technical problems could be addressed further downstream. Technical problems notwithstanding, the lack of a more effective joint management structure led to the program's inability to control costs (GAO, 2003).

In March 2005 Congress mandated the creation of a more unified structure, the Joint Program Executive Office (JPEO), to coordinate development of the "siloed" radio technologies. Unlike the JPO, where program managers reported to their own service executives, the JPEO was a well-defined management hierarchy headed by a Joint Program Executive Officer. The JPEO was a significant improvement; it centralized JTRS operations, reduced the scope of the program, revised deadlines, and was able to acquire additional funding. In addition to the creation of radio-specific (as opposed to military service-specific) programs, the JPEO implemented an incremental approach to product development, thus permitting operational experience to inform future product requirements. The JPEO separated variants and components into phases, permitting subsequent iterations to incorporate proven technologies or design successes. The JPEO also encouraged development of transitional radios to bridge the gap between current communications capabilities and the full implementation of JTRS.

The restructured JTRS JPEO currently manages four Major Defense Acquisition Programs (MDAPs): The Handheld, Manpack, and Small Form Fit (HMS); the Airborne, Maritime, and Fixed Station (AMF); the Multifunctional Information Distribution System (MIDS); and the Network Enterprise Domain (NED). The HMS program includes all portable ground radio variants that are not mounted on vehicles. AMF will overhaul the numerous communications systems currently used by the military on fixed and rotary wing aircraft, ground installations, and a wide range of warships and submarines. The MIDS JTRS program is working to transform the existing MIDS Low Volume Terminal (MIDS-LVT)—a jam-resistant, single channel secure voice and data non-software-defined radio—into a four-channel JTRS version to be used in different types of aircraft, ships, and ground stations. Finally, the NED program develops the waveforms and provides the common networking services solutions to the other programs. A fifth MDAP, the Ground Mobile Radio (GMR), was canceled in October 2011 following a sharp reduction in quantity that led to an increase in the per-unit cost of the radios (Brewin, 2011b). GMR was a four-channel radio that was to provide multimedia communications over independent channels to ground vehicle platforms. Prior to the cancellation of GMR, the DoD estimated that it would spend over $23 billion over the coming years to procure some 194,000 JTRS radios (Harrison, 2010). It is unclear if these funds will be reallocated or reduced in light of the elimination of the GMR program.

A number of lessons learned have emerged during the course of the program.

Upfront systems engineering is critical

Although JTRS was conceived as a holistic, enterprise-wide communication infrastructure, no enterprise-wide systems engineering master plan was ever devised; accordingly, there was little regard for how a certain radio, application, or other component might be integrated into the network.

Leverage the advantages of competition

The strategy used by JPEO to procure transitional radios facilitates competition, which has led to cost savings and increased efficiency, as well as performance and reliability gains. It is also promoting competition between JTRS programs.

Adopt an evolutionary acquisition strategy

It appears that within the DoD, there is a strong aversion to partial solutions. In the case of JTRS, capabilities were not assigned to specific increments; rather, they were frontloaded onto the initial requirements document. By adopting an evolutionary approach, essential technologies can be fielded in the near term, delaying the instantiation of more time intensive, costly, or technically challenging capabilities.

The acceptance of SCA as a commercial standard offers significant benefits

The success of SCA can be attributed, in part, to its acceptance as a commercial standard. SCA is now the de facto standard for all software-defined radios; it has been endorsed by the Software Defined Radio Forum and the Object Management Group, both well-known standards bodies.

An open systems architecture does not obviate the need for planning

The JTRS program's failure to define the specific limitations of the available technology, and, instead, rely on a "responsive" and "flexible" architecture, inculcated the belief that difficult technical problems could be addressed at some other point in the development process.

Concurrent development can be problematic

The concurrent development of software and hardware contributed significantly to the cost overruns and schedule setbacks that the JTRS program has encountered since its inception.

Inadequate process alignment leads to inefficiencies

The system of checks and balances that is built into the acquisition cycle, while necessary, is in conflict with organizational and cultural inertia and biases.

Governance structure is important

As discussed earlier, the original clusters approach lacked a cohesive enterprise perspective and led to decentralized program execution. The result was a program that was not achieving the overall program objectives, which led to significant cost increases.

While some JTRS variants have entered the production and fielding phases, program continuation is impacted by a growing commercial SDR market (a positive development), reductions in defense spending, and decreased demand among the services for JTRS radios. None of this is to suggest that the JTRS program has "failed" or that the DoD should never have become involved in the development of SDR technology. Today's private market SDRs all rely on the Software Communications Architecture, the development of which was funded by the military. The same can be said with regard to software development. In both cases, the DoD stands to gain from the “dual-use” benefits associated with higher production volume (i.e., lower cost and greater reliability).

As the U.S. economy, still reeling from the recession of 2008, continues along the path to recovery, lawmakers are searching for ways to cut spending to reduce the country’s $14.5 trillion debt. As top military leaders confront budgetary constraints, it seems likely that DoD investment in technologies for which a commercial market exists will decline significantly. This seems especially true of JTRS. The sharp decrease in demand among the services for DoD-manufactured JTRS radios, spurred by poor performance and escalating costs, has resulted in increased per-unit costs. As a result, the user community may look to the commercial sector to fill their communications requirements.

Given this budgetary environment and the increased political pressure to reduce defense spending, the DoD must improve the efficiency with which it develops, acquires, and fields large-scale, enterprise-wide systems such as JTRS. To that end, the following recommendations are intended to improve the JTRS program and are applicable to the development, acquisition, and fielding of other large-scale, enterprise-wide military information systems.

- **Centralize program governance**

  In order to successfully control costs, oversee the creation of a systems engineering master plan, ensure process alignment, and implement an enterprise-wide evolutionary approach to acquisition, a central authority must be established prior to the launch of the program.

- **Insist on upfront systems engineering**

  It is imperative that an enterprise-wide systems engineering master plan be devised prior to the launch of a large-scale communications system. It is not enough to rely on open standards, an architecture’s flexibility, or a system’s “plug and play” or “responsive” design.

- **Use history as a guide**

The JTRS predecessor, the SPEAKeasy radios were of limited value because wideband waveform capability, reprogrammable cryptology, and multi-channel operation were never implemented because of unforeseen cost increases and technical difficulties. JTRS has faced these same three challenges.

- **Align the various processes within the acquisition hierarchy**

The processes within the DoD acquisition process must be aligned with the end game. Realization of the master plan should be the driving motivation behind every entity within the hierarchy.

- **Maximize the benefits of competition during all program phases**

Competition, built in from the beginning of acquisition planning, is critical to ensure that its benefits can be harnessed throughout the process. Because of the current, phased design and development requirements for system acquisition, natural cutoff points exist for competition to be introduced into the process.

- **Fund DoD programs at the enterprise level**

In an effort to better align the processes within the acquisition hierarchy, JTRS, and other large, enterprise-wise programs, should be funded at the enterprise level. This will allow executives to allocate and divert funding based on a program's progress in meeting its objectives.

- **Effectively communicate objectives to all program stakeholders**

The transformative capabilities of a networked communications system were never clearly articulated to program stakeholders. The degree to which the different variants were to be interoperable was also never specified.

Some critics have remarked that JTRS is in danger of being terminated by the DoD. But even if certain JTRS MDAPs are canceled, there is no question that their equivalents will emerge eventually in the form of rebranded DoD programs or commercially produced products. Thus, the question is not so much where the DoD is going with regard to its future communication system, but how it is going to get there. Strengthening partnerships between private industry and the DoD is certainly part of the answer. Furthermore, incremental development, better process alignment, and increased accountability can all be implemented to hasten, in a cost-effective manner, the realization of the JTRS vision.

I. Introduction

In 1997 the Department of Defense (DoD) launched the Joint Tactical Radio System (JTRS; pronounced “jitters”) program to provide the military services with advanced networking communications. Simply put, JTRS was conceived “to put the entire joint force on the same wavelength” (Thompson, 2007, p. 1). Currently, the military relies on 25 families of radios that, for the most part, are incompatible and render inter-service communication (as well as mixed voice and data communication) difficult and costly. JTRS radios, however, are *software-defined* and function more like computers than conventional radios. Users can reprogram them to transmit and receive a number of different waveforms (i.e., specific pairings of frequency and signal strength). As an illustration, one might compare the JTRS software to the Microsoft Windows operating system and the waveform to an application, such as Word (Button, 2010). Ideally, users would simply push a button or turn a knob to access a different waveform. The end result will permit warfighters and support personnel to seamlessly transmit voice and data via a high-capacity wireless network using a single device. It has been suggested that the communication options will resemble those currently available to any iPhone user (Thompson, 2007). As an additional benefit, JTRS will be fully interoperable with legacy radio systems, the Pentagon’s Global Information Grid, and the communications systems of some allied nations. Because the system is software based, new applications and waveforms can be added to the radios with relative ease and at minimal expense, much like updating a software application on a personal computer.

Since the program’s inception, however, DoD officials have consistently overestimated the ease with which various components of JTRS could be developed and integrated. This has resulted in a program that has experienced delays, unforeseen technical hurdles, and major cost overruns. Development costs alone, originally budgeted at $3.5 billion, exceeded $6 billion by 2008 (Government Accountability Office [GAO], 2008). The Government Accountability Office (GAO) asserts that the early problems were largely the result of beginning system development with immature technologies, unstable requirements, and aggressive schedules (GAO, 2008). In response to a 2005 congressional mandate, the DoD established the Joint Program Executive Office (JPEO) to strengthen JTRS program management. This has led to a number of improvements in terms of cost decreases and shortened development cycles; however, the scope of the program has also been reduced substantially.

More recently, the Air Force and Navy indicated that they plan to eliminate their development programs on account of increasing costs and budget cuts. The Army followed suit, reducing procurement of the JTRS Ground Mobile Radio (GMR) by $15 billion, cutting its order from 86,209 units to 10,293 (Hoffman, 2011). This led to the GMR program's cancellation, since per-unit costs increased dramatically as a result (Brewin, 2011b). It is unclear whether the services intend to use a different technology, revert to conventional legacy radios, or purchase JTRS-compliant components from the commercial sector once the technology is sufficiently mature.

The JTRS program represents an ambitious effort to provide transformative, perhaps even revolutionary, networking capabilities to today's warfighter. A program of this magnitude and complexity presents an ideal opportunity to study the execution, evolution, challenges, and successes of a large-scale, enterprise-wide military communications acquisition. This report takes advantage of this opportunity by (1) describing the background conditions and impetus behind the creation of the JTRS program, (2) analyzing the initial acquisition strategy, (3) discussing the challenges that the restructured program office continues to face, and (4) offering a series of lessons learned and recommendations going forward.

II. Background

During the Cold War, military planning was relatively stable, predictable, and consistent. The DoD employed a threat-based planning approach to prepare for possible conflict with the Soviet Union and its allies. Strategies were designed and implemented to ensure that the military could survive a nuclear attack, sustain operations, reconstitute, and retaliate (Bonser, 2002). To that end, the military focused its efforts on augmenting the durability of its communications systems. For example, military engineers designed radios capable of operating at ultra-low frequency bands, and antennas were buried deep underground to provide survivable command and control of nuclear weapons. The future need for real-time joint communications capabilities was, perhaps understandably, not a top priority. But even during this period of relative stability, the lack of reliable, interoperable radio communications hindered the military's ability to effectively conduct joint, conventional operations.

During the 1983 U.S. invasion of Grenada, for example, uncoordinated use of radio frequencies impeded communication between Marines and Army Rangers. In what is now the most illustrative example of military communications failure, an Army Ranger whose unit was taking fire from Grenadian resistance forces had to use a calling card to place a long-distance telephone call to Fort Bragg, North Carolina to request air support. His message was relayed via satellite, and an AC-130 gunship responded. Following the Grenada invasion, the DoD asserted the need for better communications and coordination among the four military services. This led, in part, to the passage of the Goldwater-Nichols Act, which modified the command structure of the military by increasing the powers of the Chairman of the Joint Chiefs of Staff, thereby recognizing the importance of a unified, joint force.

The fall of the Soviet Union led to a brief period of military retrenchment as the nation demanded to reap the benefits of the "peace dividend." However, the threat from the proliferation of weapons of mass destruction, terrorists, rogue states, failed states, and other non-state actors became prominent national security concerns, requiring new strategies. As a result, the United States military began to engage in a variety of less traditional missions, including counter-terrorism, peacekeeping, humanitarian assistance, disaster relief, drug interdiction, border patrol, and nation building. The Goldwater-Nichols Act (1986) proved instrumental in improving and increasing the joint coordination necessary to meet these new challenges. However, there was still a failure to adequately address communications interoperability from a technical standpoint. To this day, the military relies on over 200 types of radios, the majority of which are unique and noninteroperable. The logistics infrastructure to maintain each of these systems requires "unique operator and maintainer training; documentation, spares, test and maintenance equipment … and cables, connectors, and parts," all of which come at a considerable cost (Hoffmeyer & Bonser, 1997, p. 2).

During the Persian Gulf War, the first major military conflict of the post–Cold War era, the crippling effects of an inadequate tactical communications capability were again highlighted. A 1992 congressional report revealed that soldiers "just outside shouting range of each other" were unable to communicate by radio, while pilots from different services could not speak to each other using encrypted communications and were forced to communicate in "the clear" (U.S. House of Representatives Committee on Armed Services Report, 1992, p. xi). It is estimated that 17% of the war's U.S. casualties resulted from friendly fire, sometimes referred to as "fratricide" (Steinweg, 1995). The report concluded that the major challenge for the future was to ensure that U.S. forces have the ability to communicate with one another. The scope of this resolution would broaden significantly over the next few years as inter-service communication, initially conceived as a self-contained problem, was interwoven with the evolving concept of Network Centric Warfare.

Network Centric Warfare

The Information Age has ushered in rapid advances in technology, that when leveraged for military missions, could help to ensure success. The cost of this benefit is increased complexity. The information available and subsequently required by U.S. forces has grown significantly in volume and has become more specific and more diverse (Alberts, Garstka, & Stein, 2000). As a result, the military's long held operational mantra "location, location, location" was subsumed by a new concept: "information, information, information" (Kimura, Carden, & North, 2008). The term Network Centric Warfare (NCW) emerged to describe the translation of information superiority into combat power through the effective linking of "knowledgeable entities" within a given battlespace (Alberts, Garstka, & Stein, 2000). It was envisioned that this linking or "networking" of virtually all battlefield entities would serve to accelerate "engagement cycles and operational tempo at all levels of the warfighting system" (Kopp, 2005, p. 3). NCW offers many advantages over traditional warfighting methods. First, individual assets are able to access information in real time without having to navigate through disparate and disconnected information conduits, allowing them to more quickly assess and respond to situations. Second, complete battlefield awareness, along with advances in precision munitions, allow for far more accurate fire placement. Third, seamless information flow allows units to act as a cohesive whole, even when assets are geographically dispersed.

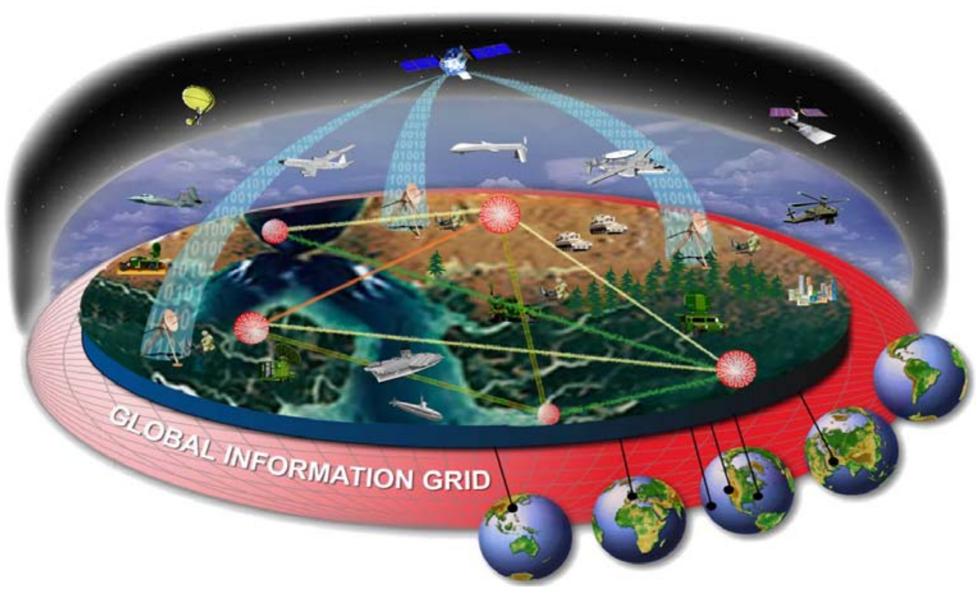

Figure 1. U.S. Military's Version of NCW, Known as Full Spectrum Dominance
(NSA, 2011)

In 1996, the Joint Chiefs of Staff released *Joint Vision 2010*, which introduced the U.S. military's version of NCW, known as Full Spectrum Dominance (see Figure 1). This conceptual template described how the DoD planned to leverage technology to achieve new levels of joint warfighting. It foretold the ability of "U.S. forces … to defeat any adversary and control any situation across the range of military operations" (Garamone, 2000, p. 1). Translating *Joint Vision 2010* from a conceptual framework into an operational reality has presented the DoD with many cultural, technical, and budgetary challenges. To be sure, “the ability to transfer information quickly across service and even national boundaries, in the fog and friction of war, using joint language that we all understand, will be nothing less than revolutionary” (Shelton, 1998, p. 1).

The DoD launched the Joint Tactical Radio System (JTRS) in 1997 to replace its aging stock of legacy radios. The program’s stated objectives were to achieve cost savings, improve performance, and provide the services with a fully interoperable communications system. In its initial years, the program underwent several requirements revisions as DoD officials began to realize the foundational role JTRS would play in the net-centric operations outlined in *Joint Vision 2010*. The JTRS program would be based on an evolving technology: the software-defined radio.

Software-Defined Radio

Conventional tactical military radios rely on a single waveform that is built into the unit’s hardware, allowing for simple short-range line-of-sight voice or text transmission. JTRS, on the other hand, is a software-defined radio (SDR), a communication system in which traditional functions (e.g., frequency, modulation & demodulation, data format, encryption, and communication protocol) are implemented through software loaded on an open, standard, and modular, general hardware platform (Dillinger, Madani, & Alonistioti, 2003). Consequently, the radio is capable of receiving and transmitting a wide variety of different radio waveforms, simply through the addition or removal of software. It is instructive to conceptualize these waveforms as computer applications like Microsoft Word or Excel. The software application, or waveform, can be added or removed from the SDR on an as-needed basis. This utility provides a significant advantage (i.e., the ability to handle multiple radio communication protocols on a single hardware platform) by means of programmable hardware controlled by software. The reprogrammable radio can store, and run, multiple waveforms. With SDRs, the military forces can have interoperable radios based on common waveforms, standards, and interfaces, as opposed to developing multiple radio systems operating with different standards.

Each SDR can be outfitted with the necessary mission-specific applications. Software-defined radios, then, have significant utility for the military, which requires access to a variety of applications. And unlike earlier SDRs, JTRS will be unique in its ability to port multiple waveforms simultaneously. In the end, JTRS will function more like a computer than a radio. Taken to the extreme, a single SDR device "could provide cellular connectivity, act as an AM/FM receiver, offer GPS position location services, connect to wireless data networks or even function as an HDTV receiver" (Vanu, 2009). And, while any teenager in the United States may have similar capabilities at his disposal, an SDR's complementary infrastructure (e.g., modem and router) is built into the unit, allowing it to operate anywhere in the world. Moreover, the JTRS network, unlike a typical wireless network, will be able to support multiple security levels.

JTRS represents the DoD's second attempt to develop interoperable software-defined radios. In the early 1990s, it began development of the SPEAKeasy program. This initiative, led by the Defense Advanced Research Projects Agency (DARPA), was intended to provide many JTRS-like capabilities, albeit to a lesser degree. For instance, these radios, though portable, were not handheld. As with JTRS, users could load different waveforms onto the device. All in all, SPEAKeasy radios were able to effectively emulate more than ten hardware-based DoD radio systems. As with JTRS, the development of this early software-defined radio was predicated on four core operating identities (see Figure 2).

Open Architecture	***Reprogrammability***	***Simultaneity***	***Interworking***
• Eliminates stovepipe solutions	• Provides the flexibility to support a variety of mission types	• Facilitates multiband, multimode operation	• Interconnects diverse radios
• Reduces cost (Purchase and lifecycle)	• Able to be modified and upgraded in the field		• Enables incremental fielding
• Provides a scalable system			

Figure 2. The Core Operating Identities of Software-Defined Radios
(*Note*. The information in this figure came from Bonser, 1998.)

During the second phase of the program, with a scheduled duration of three years, developers were to design a new SPEAKeasy prototype capable of supporting simultaneous applications (initially, an individual SPEAKeasy radio could support only a single conversation at a given time). The program met this goal after less than 15 months, at which point development was abruptly halted. DoD officials cited cost overruns as the major impediment to continuing development. In addition, DARPA wanted to transition the program to the services, which were eager to begin acquisition of the radio system "as is." Thus, the decision was made to cancel research and development in 1996 and begin the acquisition process. Unfortunately, the radios were of limited value; wideband waveform capability, reprogrammable cryptology, and multi-channel operation were never implemented, and SPEAKeasy radios were never widely produced. Fifteen years later, these three issues continue to challenge the JTRS program. JTRS has struggled to meet size and weight constraints imposed by the Wideband Networking Waveform (WNW) while the National Security Agency (NSA) security certification process has hindered the fielding of JTRS variants. Today, single-channel "JTRS-approved" radios are the only variants that have been widely fielded.

The JTRS Vision

When it became apparent that the tenets of NCW would guide military strategy into the next millennium, the JTRS program was redefined. The new objective was to provide secure, networked communications "on-the-move" and at the tactical edge. Indeed, by the year 2000, many within the DoD preferred to think of JTRS as an "information warfare communication system," as opposed to merely a radio replacement program. According to the JPEO, JTRS was reconceived to provide "a transformational communication capability for connecting all services, platforms, and coalition forces in networks with 21st century voice and data capabilities" (Kimura, Carden, & North, 2008, p.12; see Figure 3). Given the state of domestic communications networking technologies, this objective may seem easily attainable. However, a soldier's ability to access tactical maps, send text messages to his commanding officer, or reprogram weapons platforms remotely—all from a secure, distant environment with no fixed infrastructure—is a spectacular feat. As one military correspondent aptly asserts, "the only reason your laptop can go online from your table at Starbucks is that its wireless signal has to carry only a few yards to the Wi-Fi access portal built into the wall" (Freedburg, 2008, p.1).

Not only would a single JTRS radio be versatile enough to transmit using a wide variety of waveforms, but unlike its predecessor, it would be capable of porting multiple waveforms simultaneously. This would permit JTRS users to communicate seamlessly with users of conventional legacy radios, thereby maintaining backward capability. Brick and mortar command centers would no longer serve as message relay stations; rather, the dismounted ground soldier could communicate directly with the tactical fighter in the sky, or the combat ship at sea.

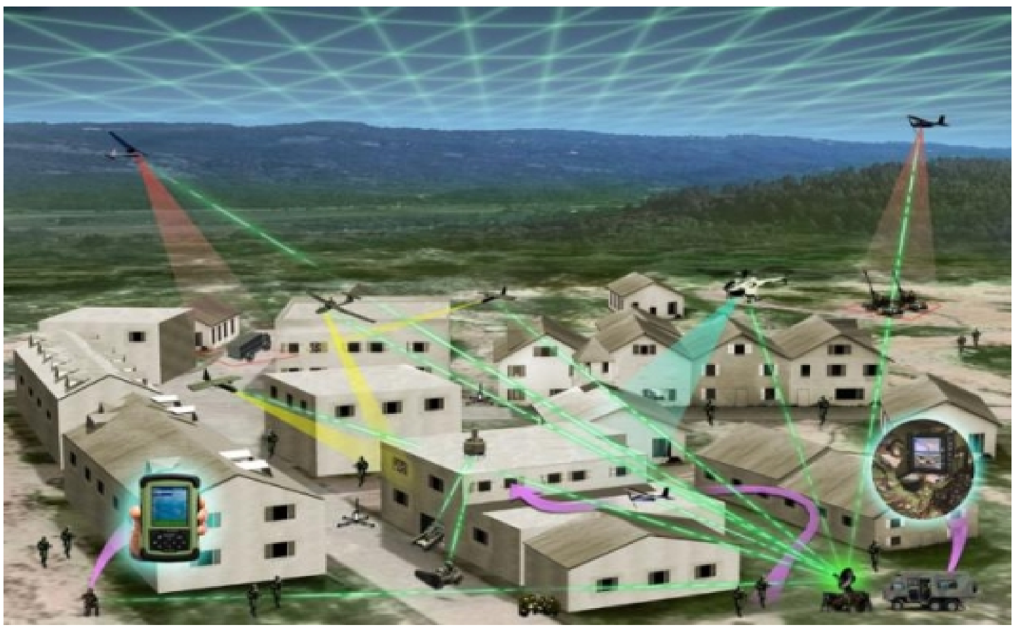

Figure 3. Transformational Communication Capability Envisioned by the JTRS Program (Gizmag, 2005)

Unlike earlier software-defined radios, JTRS would also be able to support advanced Internet Protocol (IP)-based waveforms including the Wideband Networking Waveform (WNW) and the Soldier Radio Waveform (SRW), both of which link to the Global Information Grid**—**the DoD's globally interconnected on-demand information system. Unlike legacy waveforms, which carry information via a single modality (i.e., voice, text, or picture), IP-based waveforms provide greater bandwidth so that information can be transmitted and received quickly in the form(s) most conducive to the mission at hand. In short, IP-based waveforms provide the warfighter with instant access to a wide range of mission-critical information at the touch of a button.

An open architecture framework known as the Software Communications Architecture (SCA) is key to the system's interoperability. In essence, the SCA "tells designers how elements of hardware and software are to operate in harmony" (Brown, Sticklan, & Babich, 2005, p. 1) thus enabling users of different JTRS variants (airborne, maritime, ground, fixed, etc.) to load the same waveforms and run the same applications. The goals of SCA specification include reducing the development expense by adopting existing standards and reusing components to reduce development time. Ideally, this standard will guarantee the portability of software and the reconfigurability of hardware platforms.

The SCA defines an operating environment that will be used by JTRS radios. Not only is the SCA meant to be an open and commercially adopted standard, but it is also based on, and uses, open commercial standards, such as the Common Object Request Broker Architecture (CORBA; which enables software written in multiple computer languages and running on multiple computers to work together) and the Portable Operating System Interface for Unix (POSIX). As such, the SCA encourages and facilitates "plug and play" component use and reuse, thereby permitting various software designers to manufacture waveforms using their own components. Ultimately, adoption of this common architecture will minimize portability costs while maximizing the seamless portability of one waveform among multiple platforms.

The SCA has been widely endorsed, ensuring its role as the universal standard. Furthermore, the SCA allows for design and implementation of the IP-based waveforms described above. Although the original technical concepts behind SDR originated within the DoD, based on the DoD's groundbreaking research and the development and acceptance of the SCA as a standard, it has recently gained traction in commercial markets. This should significantly benefit the DoD, both from the added competitive pressure and innovation provided by the commercial sector.

III. Initial Strategy

In December 1997 the Under Secretary of Defense for Acquisition and Technology (USD[A&T]) designated the Army as the program's lead service and acquisition executive. In October 1998, the Army established the Joint Program Office (JPO), tasked with overseeing the JTRS program. Initially, the DoD planned to develop JTRS in three phases. In the first phase, which began in late 1998, the JPO awarded contracts to three teams consisting of contractors and universities. The teams were to develop an open architecture that could be demonstrated in a laboratory environment. During Phase II, the JPO launched a competition in which each team presented its designs. The Software Communications Architecture (SCA), referenced in the previous section, was chosen in April 2001, and its design was released to major defense contractors.

Phase II also called for an analysis of then-available products and technology. Based on the analysis, completed in October 2000 and conducted in large part by the Defense Science Board, the USD (A&T) concluded that industry technology was sufficient to proceed directly into production, and that additional DoD-led research and development were not needed. The choice of a service-led acquisition strategy by the USD (A&T) in late 2000 signaled the beginning of Phase III during which the services were to begin procurement of their own radios. Note that the beginning of the final phase actually preceded JPO's adoption of the SCA by a few months. The DoD believed that the rudimentary architectures upon which exiting SDR systems had been built could guide both the ongoing architectural refinement and radio development.

An overarching structure, the JPO managed development of the SCA and most of the waveforms, the key elements behind JTRS' interoperability. Development of the radio variants was divided into five clusters, each of which was headed by one of the military services (see Figure 4).

Cluster	Lead Service	Responsibilities
1	Army	• Develop JTRS for Marine and Army ground vehicles, Air Force Tactical Air Control Parties (TACPs), and Army helicopters. • Develop Wideband Networking Waveform (WNW), a next-generation Internet protocol (IP) based waveform to facilitate ad-hoc mobile networking.
2	U.S. Special Operations Command	• Develop JTRS capabilities for existing handheld AN/PRC-148 Multi band Inter/Intra Team Radio (MBITR) to create JTRS Enhanced MBITR (JEM).
3	Navy	• Develop Multifunctional Information Distribution System (MIDS) terminals.
4	Air Force	• Develop JTRS for Air Force and Navy fixed-wing aircraft and helicopters.
5	Army	• Develop handheld, man-portable, and other small JTRS variants.

Figure 4. The Clusters Acquisition Approach
(*Note.* The information in this figure came from JPEO JTRS, 2011.)

Early Challenges

This service-led, decentralized acquisition strategy was pursued because the technology was believed to be sufficiently mature so as to begin near-immediate procurement. Existing SDR architectures, it was thought, provided the services and their chosen contractors with an adequate foundation upon which different JTRS variants could be manufactured, regardless as to who the manufacturer was or which components were used. Initially, the DoD had hoped to expeditiously replace some 750,000 existing radios, known as legacy systems, with approximately 180,000 JTRS variants over the course of a decade (Brewin, 2009). Low-rate production of Cluster 1 Ground Mobile Radios (GMR) was slated to begin as early as 2005, with development and production of other variants to follow soon after. However, technical difficulties and cost overruns hampered progress from the onset. Many of the problems can be attributed to the decentralized management structure that, in effect, stove-piped product development leading to inefficiency and, in some cases, redundancy. At the same time, this compartmentalization fostered the erroneous view that any functional gaps could be plugged at some later point with software solutions developed by JPO.

To some extent, the achievements of the SPEAKeasy program—its open system design, reprogrammable nature, and 70% commercial off-the-shelf (COTS) procurement—unduly influenced the strategy employed to acquire JTRS. The rationale behind the clusters approach relied upon the following assumptions:

- a universal, open architecture (i.e., the SCA) provides a solid foundation upon which to develop and produce interoperable JTRS variants; and
- other technologies needed to create the end products would be ancillary, easily acquired, and adaptable.

In other words, the DoD expected the open architecture "to provide the services with sufficiently developed hardware and software prototypes that they [could] use to immediately procure JTRS products" (GAO, 1999). These assumptions were tested in 2002, the year Boeing was awarded $856 million for the development, demonstration, and low-rate initial production of 10,000 JTRS Cluster 1 units.

Both the DoD and Boeing underestimated the challenge of integrating the various technologies and waveforms into units that had predetermined size, weight, and power consumption requirements (Feikert, 2009). In particular, running the Wideband Networking Waveform (WNW) required substantial amounts of memory and processing power which, in turn, required that the units be built larger and heavier than anticipated. After more than three years of development, Boeing was unable to produce a single unit meeting DoD imposed size, weight, and power requirements (GAO, 2006).

Technical challenges notwithstanding, the service-led Clusters structure engendered development redundancy. By dividing procurement responsibilities among the services, all of the costs (research, development, fielding, etc.) associated with each radio variant would be shouldered by the user of the end product. Though this strategy seemed the most equitable, it engendered a service-centric approach, rather than a DoD-wide enterprise approach, and JTRS came to be viewed as a radio replacement program as opposed to a new, holistic enterprise-wide information infrastructure. Consequently, there was no enterprise-wide systems engineering master plan; accordingly, each radio was designed to meet service-specific needs and desires with little regard for how the radio might fit within the overall network or integrate into different platforms. For instance, both Cluster 1 (led by the Army) and Cluster 4 (led by the Air Force) were tasked with the development of JTRS for their own helicopter platforms; service-specific technical requirements, it appears, provided the rationale. Similarly, JPO took on the responsibility for waveform development, but assigned the WNW, described above, to Cluster 1. Moreover, there was no plan to formally test interoperability among the five clusters. To this day, inadequately defined interoperability goals continue to present a challenge to the JTRS program.

The DoD intended to leverage commercial technology in order to rapidly procure JTRS variants. It was thought that the military's communication objectives were in line with commercial sector incentives. Any technological deficits that might surface, it was assumed, could be addressed by DARPA. However, critics of this acquisition approach alleged that the commercial sector—which relies on a fixed infrastructure in developing mobile communications (e.g., cell phone towers, routers, etc.)—was unlikely to produce the needed JTRS technology in the absence of an established market (GAO, 1999). A report released by the Rand Corporation in 1998 asserted that "although variants of commercial systems would appear to offer a middle course of action between military-unique and COTS systems, this approach is typically not practical because costs quickly approach those of military-unique systems" (Feldman, 1998, p. 45).

Not everyone agreed with the critics' cautionary approach. For example, in a 1999 House Appropriations Report, Congress asserted that decisions with regard to architecture, interoperability, and acquisition strategy should be accelerated (H.R. Rep. No. 106-244). The report also directed the DoD to prioritize legacy radios for replacement. The Defense Science Board (DSB) Task Force released a study in 1999 that stood in stark contradiction to critics' assertions. The Task Force members stated that they were "struck … by a sense that [the Office of the Secretary of Defense] and the services did not appreciate the magnitude of the potential impact of the JTRS" (DSB, 1999, p. D-6). In one of their recommendations, the Task Force suggested that JTRS be renamed the Joint Tactical Communications System to emphasize its transformative networking capabilities.

The services were, understandably, more concerned with replacing their ageing legacy radios—many of which dated from the Vietnam era—than embracing a nebulous communications paradigm. Indeed, all four of the services cited the need for near-term solutions. The DSB Task Force concluded that "each 'dissenting' organization was basing its views on the 'perceived' cost of, and length of time until, JTRS units would be available" (DSB, 1999, p. D-6). The Task Force issued a strong objection to the services' reluctance. In their study, they wrote the following:

> The Task Force members, based on the contractor briefings and the detailed experience of several members in developing JTRS-like systems, *see no technical show-stoppers* with respect to developing the JTRS. In fact, the Task Force feels that the JTRS can be put on *a much more aggressive acquisition cycle* than is presently envisioned by OSD and the Joint Program Office (JPO). The present strategy of "acquiring an architecture" first and then a brassboard JTRS in several years is much too modest a goal. (Emphasis added; DSB, 1999, p. D-7)

The Task Force went on to state that accelerating the acquisition of JTRS would present "only modest risk," and reckoned that the first set of radio variants could be acquired within 12 to 14 months (DSB, 1999, p. D-7). In hindsight, it is clear that the Task Force's expectations for success were not only ambitious, but also optimistic. At the same time, it might be said that its efforts to redefine JTRS as a transformative communications system—and not a radio replacement program—has helped shape the program's evolution for the better, providing meaningful direction and infusing it with a greater sense of purpose.

Unrealistic Expectations

In one of its initial recommendations, the GAO suggested that the JPO develop a technology plan that "included specific limitations of commercial and DoD technology in satisfying current and future JTRS requirements" (GAO, 1999, p. 16). In response, the DoD issued the following statement:

> The GAO recommendation is inconsistent with the precepts of the JTRS program. The original JTRS philosophy as depicted in the Operational Requirements Document … is for industry to provide the best possible solutions for the JTRS family of radios via an open systems architecture. This open systems architecture is responsive by nature to changes in technology and is flexible in design to accommodate technological advances in software and hardware. (GAO, 1999, p. 29)

As the focus of the JTRS program transitioned from radio replacement to transformational networked communications, technical requirements were modified. "Requirements creep," or the continual enhancement of the requirements of a project as the system is being developed, is a serious problem that has delayed JTRS since its inception. More waveforms were added to the JTRS repertoire; power consumption, size, and weight requirements of several JTRS variants changed dramatically. Simply put, none of the services had a firm understanding of what a finished JTRS product might look like. In hindsight, it appears that the program's failure to define the "specific limitations" of the available technology and, instead, rely on a "responsive" and "flexible" architecture inculcated the belief that difficult technical problems could be addressed at some other point in the development process. By the end of 2005, the inherently flawed approach and the resulting technical and managerial challenges brought the JTRS program to a standstill.

Legacy Radio Spending

In 2002, when the first software-defined radio variants were entering early development, the DoD planned to invest approximately $3 billion in JTRS over the course of five years in order to equip the services with JTRS radios. While only $2.5 billion was actually spent on the program during this time period, close to $6 billion was spent acquiring legacy systems, $5.5 billion of which came in the form of supplemental funding. Initially, service acquisition executives were required to submit waiver requests in order to purchase non-JTRS radios. (In an April 1998 memorandum, the Under Secretary of Defense (A&T) directed the services to suspend development and acquisition of all non-JTRS systems) (GAO, 1996). At first, such waivers were granted on a very limited basis, with a total of nine waivers being issued between April 1998 and

June 1999. However, these waivers became more common and eventually little more than a formality.

Upon JPO's failure to deliver sufficiently developed hardware and software prototypes to the services prior to an October 2000 deadline, the number of DoD-issued waivers increased considerably. Indeed, by May 2005, not a single JTRS radio prototype had met the DoD's stringent operational requirements. The initial goal of providing JTRS capabilities to the services by 2007 proved unattainable, and with growing demands to adequately equip troops in Iraq and Afghanistan with working radios, the waiver process was canceled. The recently purchased legacy radios have a shelf life of 10 to 15 years. Accordingly, demand among the services for JTRS radios is down dramatically as it is difficult to justify the early retirement of functional radios.

IV. Program Restructuring

The initial procurement of JTRS radios (i.e., Phase III) came to a halt in 2005 because of program cost overruns and insurmountable technical hurdles. No radios had been fielded. By 2006, the service-led Clusters approach had been eliminated entirely. Congress believed that the lack of a joint management structure led to the program's inability to control costs. In March, 2005, Congress mandated the creation of a unified structure, the JPEO, to coordinate development of the siloed radio technologies (GAO, 2003). Unlike the JPO, where program managers reported to their own service executives, the JPEO was a well-defined management hierarchy headed by a Joint Program Executive Officer, who, in turn, reported to the Under Secretary of Defense (A&T).

In April, 2005 the DoD issued Boeing a "show cause" letter stating that its contract might be terminated because of anticipated failures to meet cost, schedule, and performance requirements. Of the $856 million, $573 million had been spent. Worried that Boeing's problems stemmed, in part, from an ineffective JTRS management structure, the newly created JPEO centralized JTRS operations, reduced the scope of the program, revised deadlines, and added funding. In March 2006, this new structure, consisting of four "domains," replaced the service-led clusters approach (see Figure 5).

Domain	Responsibilities
Ground	• Develop communications and networking capabilities for vehicles, dismounted soldiers, sensors, and weapons systems
Airborne, Maritime, Fixed Site	• Develop communications and networking capabilities for aircraft, ships, and ground fixed site platforms, and a JTRS radio to replace the Multifunctional Information Distribution System terminals on selected platforms, including the F/A-18 aircraft.
Network Enterprise	• Develop waveforms, gateways, and common networking services solutions
Special Radios	• Develop JTRS Enhanced Multi-Band Intra-Team Radio used by Special Operations Forces.

Figure 5. Program Domains Within the JTRS Joint Program Executive Office
(*Note.* The information in this figure came from JPEO JTRS, 2011.)

In addition to the creation of these new domains, the JPEO implemented an incremental approach to product development, thus permitting operational experience to inform future product requirements. The JPEO separated variants and components into phases, permitting subsequent versions to incorporate proven technologies or design successes. The JPEO also encouraged development of "transitional radios" (e.g., Consolidated Single Channel Handheld Radios [CSCHR]), which are considered "JTRS approved," indicating that they are National Security Agency certified, JTRS technology laboratory certified, Joint Interoperability Command certified, and Software Communications Architecture compliant, but that they lack the capacity to load multiple waveforms (Zaverelli, 2009).

A New Approach

In addition to programmatic restructuring, the JPEO assessed the entire program to determine the source of the cost overruns and schedule delays. The JPEO determined that (1) requirements creep destabilized the development process, (2) complex information security problems were not anticipated, (3) initially conceived as a legacy radio replacement program, JTRS was never re-baselined to meet the network-centric demands, and (4) the program was operating with high schedule, technical, and cost risks.

Cost-performance tradeoffs are a central feature of the JPEO's new evolutionary approach. Accordingly, the production of many costly non-essential, or non-transformational, requirements was deferred to later increments. Four major requirements were either lessened or deferred to later increments (GAO, 2006).

1. The first increment of waveforms was reduced from 32 to 11. The rest were deferred to later increments and are all non-networking legacy waveforms. This adjustment allowed the JPEO to focus on developing and testing the critical networking waveforms and reduce software translation efforts.

2. The first increment of radio variants was reduced from 26 to 13, reducing the amount of time and money required to design hardware and integrate platforms prior to the release of the first, most critical variants.

3. The number of waveforms to be operated simultaneously by a radio variant was reduced. Initially, it was planned that most waveforms would operate on most radios. However, it was realized that providing this capability to all radio variants would be costly and time consuming. Reducing the number of waveform combinations per variant allows size, weight, and power requirements to be met more easily.

4. External infrastructure was built to facilitate network interoperability. Initially, individual JTRS radios were to be capable of seamlessly transmitting and receiving information carried on different waveforms. However, the technology enabling this functionality is not yet mature. Accordingly, gateway devices (which are external to the JTRS radio) are being developed to convert waveforms into readable form.

JTRS Programs of Record

Currently, the JTRS program comprises four Major Development Acquisition Programs, or MDAPs[1], each of which is assigned its own program manager: the Handheld, Manpack, and Small Form Fit (HMS); the Airborne, Maritime, and Fixed Station (AMF); the Multifunctional Information Distribution System (MIDS); and the Network Enterprise Domain (NED). Each of these programs is housed within one of three domains. The HMS program is in the Ground Domain, the Airborne, Maritime and Fixed Site Domain oversees the AMF and MIDS programs, and the NED domain is its own MDAP, though it is divided into two sub-categories: the Network Enterprise System and Waveforms. Prior to its cancellation in October 2011, a fifth MDAP, the Ground Mobile Radio, was included in the Ground Domain. The domain structure provides another layer of oversight, in that similar programs (e.g., the two that are developing radios for airborne platforms) are assigned an intermediate level of management (see Figure 6).

[1] An MDAP is defined as a program estimated by the USD (Acquisition, Technology, and Logistics) to require eventual expenditure for research, development, test, and evaluation of more than $365 million (in year 2000 constant dollars) or procurement of more than $2.19 billion (in year 2000 constant dollars).

The Special Radios Domain, depicted in Figure 6, was eliminated in 2009. However, the domain's only program, the JTRS-enhanced MBITR (JEM) is now an integral component of the Ground Domain's transitional JTRS radio program, known as CSCHR. Note that in Figure 6, some of the MDAPs are referred to as "products" (e.g., HMS). Whereas the MDAP designation reflects the cost of development and procurement of the given program, Figure 6 illustrates the technical and managerial relationships—irrespective of cost—among the various radios. For the purposes of this analysis, programs will be discussed with regard to their MDAP designations.

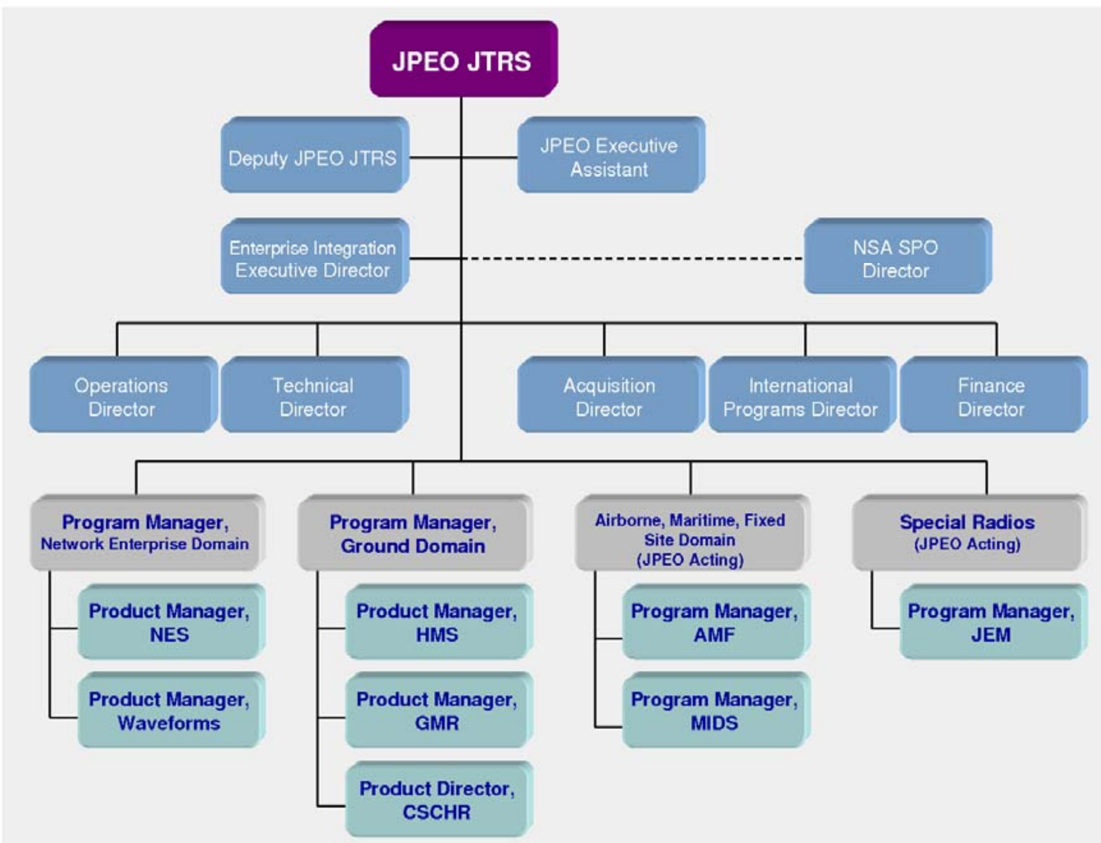

Figure 6. JPEO Organizational Structure
(JPEO JTRS, 2011)

Handheld, Manpack, Small Form Fit (HMS)

Formerly a part of Cluster 5, the HMS program includes all portable ground radio variants that are not mounted on vehicles (see Figure 7). Specific to HMS is its use of the high bandwidth

Soldier Radio Waveform (SRW). Whereas NED had produced software-based waveforms to mimic, and indeed, interoperate with legacy waveforms, the SRW is the first of the new generation of waveforms, as it exists only in software form.

Figure 7. JTRS Handheld, Manpack, and Small Form Fit Radios: Small Form Fit D (top), Small Form Fit B (middle), Manpack, and Rifleman Handheld Radio
(JPEO JTRS, 2011)

Overall program cost, cost per unit, and quantity remained steady during the initial four years of development. In 2008, the demand for HMS radios fell precipitously, partially in response to the increased fielding of JTRS-approved single-channel hand-held radios (i.e., CSCHR) and commercial vendors' radios (all of which are SRW-compatible; see Figure 8). In 2009, revised estimates revealed that the HMS program had increased cost efficiency considerably because the cost per unit dropped from approximately $26,000 in 2004 to close to $19,000 by 2010. As of August 2011, the Army planned to purchase more than 190,000 Rifleman radios and approximately 50,000 Manpack radios.

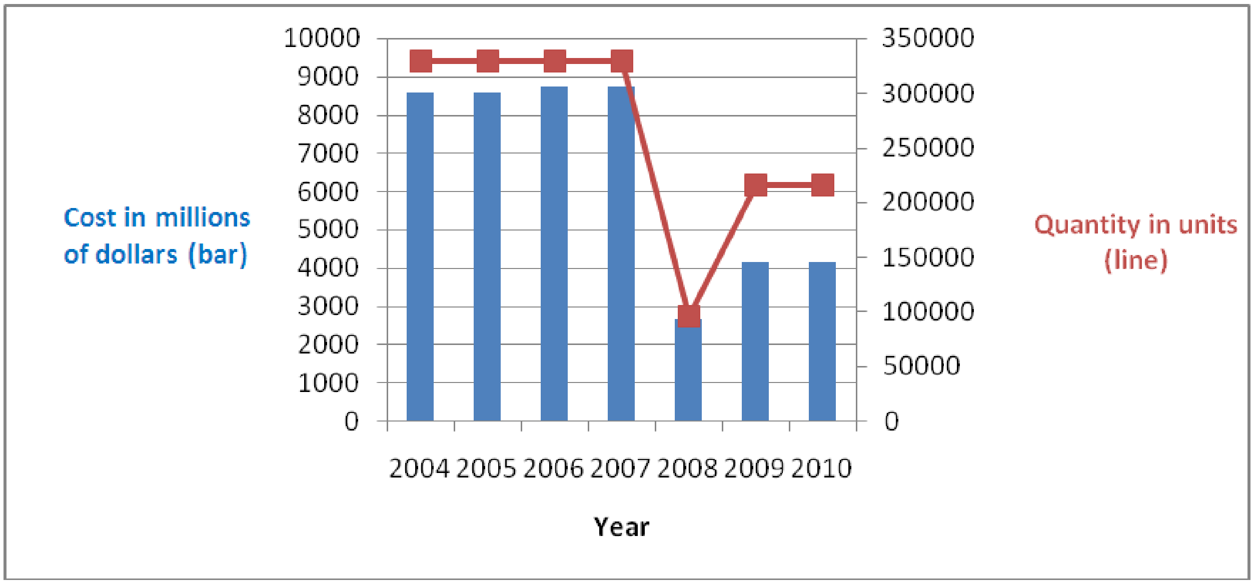

Figure 8. Changes in HMS Program Cost (in constant dollars) and Quantity
(*Note*. The information in this figure came from Selected Acquisition Reports, 2004-2010.)

Airborne, Maritime, and Fixed Station (AMF)

The AMF program will overhaul the numerous communications systems currently used by the military on fixed and rotary wing aircraft, ground installations, and a wide range of warships and submarines (see Figure 9). Of all the JTRS programs, AMF has experienced fewer cost overruns and technical setbacks in part because the AMF program did not commence in earnest until after the JTRS program was restructured in 2006. By this time, the SCA had been well established, and many of the initial challenges described in Section III had been overcome. Accordingly, AMF began operating with modest risk.

Figure 9. JTRS Airborne Maritime and Fixed Station Radios: Maritime Fixed JTR (left) and Small Airborne JTR (right)
(JPEO JTRS, 2011)

Multifunctional Information Distribution System (MIDS)

The MIDS-JTRS program is working to transform the existing MIDS Low Volume Terminal (MIDS-LVT)—a jam-resistant, single channel secure voice and data non-software-defined radio—into a four-channel JTRS version to be used in different types of aircraft, ships, and ground stations. MIDS-JTRS has been characterized as a form, fit, and functional replacement for the MIDS-LVT by the JPEO (see Figure 10). MIDS-JTRS will include all of the older system's capability in addition to increased functionality. Most significantly, the JTRS version will have three additional channels, thus permitting the simultaneous porting of multiple waveforms, including those currently being developed by NED. Five nations (U.S., France, Germany, Italy, and Spain) partnered to create the original MIDS-LVT system, which provides interoperability with NATO users. MIDS-LVT terminals have proven highly effective in enhancing communication among allied forces in the recent conflicts in Iraq and Afghanistan.

Unlike its predecessor, MIDS-JTRS is not a multinational partnership, though the new radio will be able to interoperate with MIDS-LVT. Since 2004, however, MIDS-JTRS program costs have increased steadily from a budgeted $304 million to more than $707 million by 2010 (GAO, 2010). As a result, many of the program's intended users have become reluctant to adopt the system. The program was suspended in 2007 pending a determination as to whether there were enough potential users to support further development.

Figure 10. Multifunctional Information Distribution System—JTRS
(JPEO JTRS, 2011)

Network Enterprise Domain (NED)

The JTRS Network Enterprise Domain is responsible for the development of the three primary networking waveforms—the Wideband Networking Waveform (WMW), Soldier Radio Waveform, and Multi-user Objective System (MUOS)—as well as the software design of 14 legacy waveforms, such as Single Channel Ground and Airborne Radio System, Link 16, and ultra-high-frequency satellite communications. In addition, NED oversees network management and integration. In April 2010, NED awarded the JTRS Enterprise Network manager contract. This new contract consolidated the activities of independent network managers aligned with each waveform. The objective was to ensure that combat units could securely communicate with each other seamlessly over multiple waveforms on any JTRS radio.

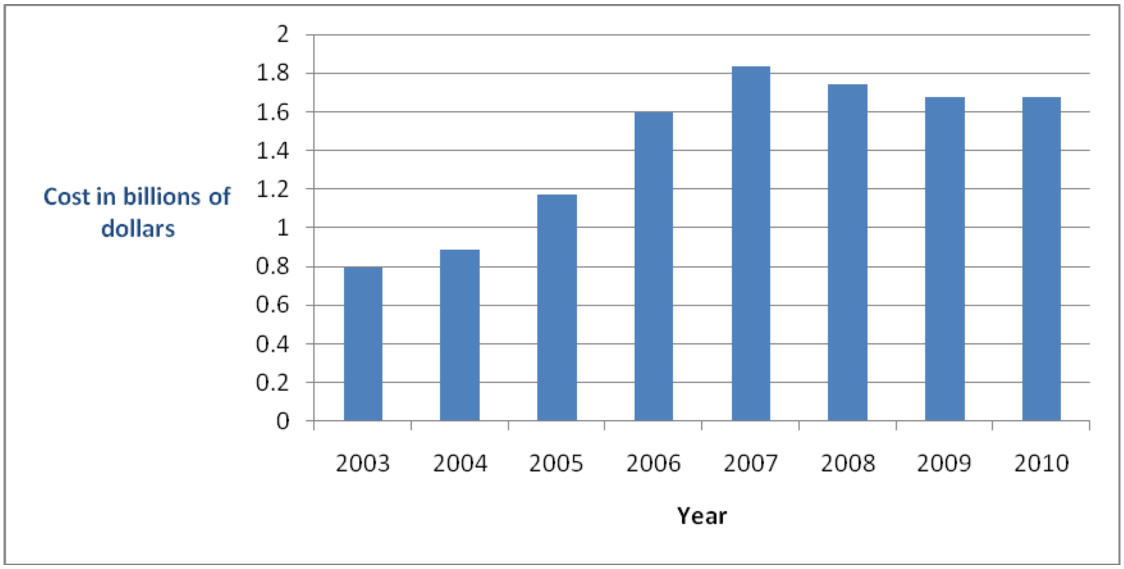

Figure 11. Changes in NED Program Cost (in constant dollars)
(*Note*. The information in this figure came from Selected Acquisition Reports, 2003-2010.)

The costs associated with waveform design and implementation have increased significantly since the NED was created in 2006 as part of the congressionally mandated restructuring. For example, between 2003 and 2005, when all NED-related activities fell under the umbrella of Cluster 1, total NED-related costs increased steadily by close to $400 million. After the restructuring, costs climbed to approximately $1.8 billion by 2007. Over the course of seven years, between 2003 and 2010, nearly a billion dollars had been added to the total cost of the program. At the same time, the total number of waveforms planned for development during this period was reduced, as mentioned earlier, from 26 to 13.

Ground Mobile Radio (GMR) (Cancelled)

In December 2001, Boeing submitted a proposal to the Army for System Design and Development (SDD) of Cluster 1 radio variants, which included what would later be known as the Ground Mobile Radio: a four-channel radio providing secure and simultaneous multimedia communications over independent channels to ground vehicle platforms (JPEO JTRS, 2011; see Figure 12). In June 2002, the Army (which headed Cluster 1) awarded Boeing a six-year $856 million contract for SDD and Low Rate Initial Production (LRIP) of up to 10,000 ground and airborne units. Additionally, Boeing would be responsible for the integration of the JTRS architecture, the integration of legacy waveforms, and development of the WNW.

Figure 12. JTRS Ground Mobile Radio
(JPEO JTRS, 2011)

The total cost associated with the development and procurement of GMR was originally estimated at $14.4 billion. This amount was to cover production of 108,388 units. Figure 13 displays the fluctuations in cost estimates and quantities through 2010.

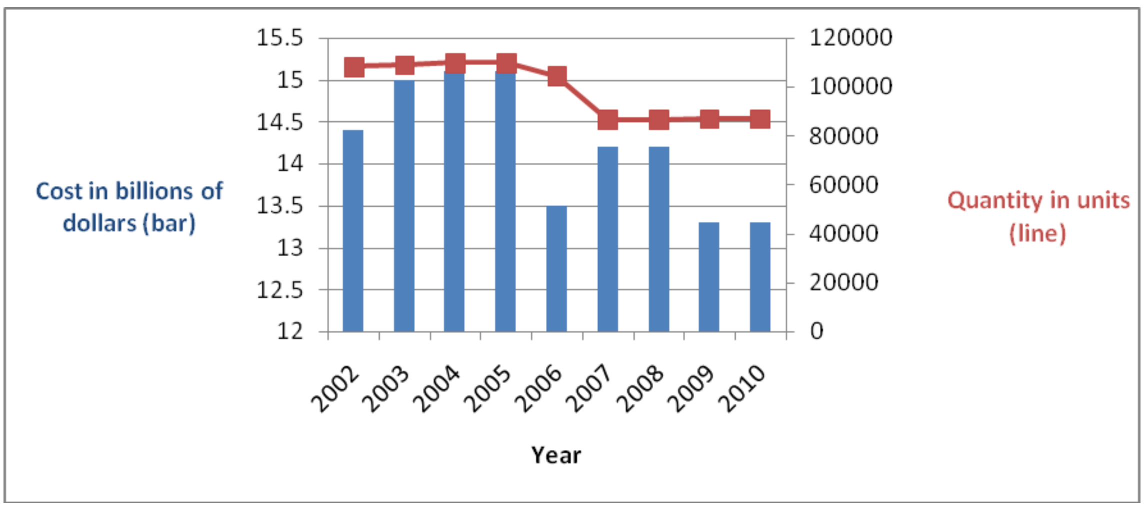

Figure 13. Changes in GMR Program Cost (in constant dollars) and Quantity
(*Note*. The information in this figure came from Selected Acquisition Reports, 2002-2010.)

In March 2006, the JPEO centralized program management, extended deadlines, and added funding but reduced the scope of the JTRS program. As a result, JTRS GMR decreased its overall production objective by close to 4,000 units. Decreased demand among the services brought on by budgetary constraints and declining confidence in GMR's development trajectory led to further reductions in quantity in 2007. For a brief period, between 2009 and 2010, it appeared that GMR would be able to control costs, in that the total estimated cost of the program seemed to be falling faster than the reduction in quantity (see Figure 13).

More recently, however, in mid-2011, a series of tests conducted by the Army revealed a number of problems with GMR, including poor support for secure voice networks, limited range of transmission, difficulties connecting to sensor fields, and an overall lack of reliability (Director, Operational Test and Evaluation [DOT&E], 2010). In addition, limited battery life—a problem noted early on when GMR was part of Cluster 1—continues to pose a problem. In April of 2011, the Space and Naval Warfare Systems Command (SPAWAR), at the behest of the JPEO, announced its intention to seek commercial alternatives to the JTRS GMR. SPAWAR planned to purchase between 10,000 and 25,000 commercial ground units between 2013 and 2025, provided they proved superior to the GMR product (Brewin, 2011a). SPAWAR's announcement was made in anticipation of the GMR program's spiraling costs brought on, in part, by the cancellation of the Army's Future Combat Systems (FCS) program in 2009.[2] All but 1,000 GMR units were to be mounted on Army vehicles, a significant portion of which were to be newly manufactured as part of FCS. The following month, in May 2011, GMR per unit costs rose dramatically after the Army cut its GMR order from 86,209 units to 10,293, triggering a Nunn-McCurdy breach, which brought the program to a standstill.[3] At this point, the estimated total cost of the program had risen to $15.9 billion (Brewin, 2011b). In October 2011, the JTRS GMR was officially cancelled.

Transitional Radios

In 2007 the JPEO broke with tradition and issued an Indefinite Delivery/Indefinite Quantity (IDIQ) contract to cover acquisition of Consolidated Interim Single Channel Handheld Radios (CISCHR). Through a single contract, the services were able to choose among different companies' "JTRS Approved" handheld radios, "enabling economies of scale and competitive pricing at the acquisition level" (Baddeley, 2010, p. 1). Upon meeting capabilities requirements, both Thales Communication and Harris Corporation were provided funds to cover first-year

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[2] Formally launched in 2003, FCS was envisioned to create new brigades equipped with new manned and unmanned vehicles linked by an unprecedented fast and flexible battlefield network (Olson, 2010).

[3] A Nunn-McCurdy breach is triggered when the per unit cost of a defense project exceeds initial estimates by more than 25%. The program is terminated unless the Secretary of Defense "submits a detailed explanation certifying that the program is essential to the national security, that no suitable alternative of lesser cost is available, that new estimates of total program costs are reasonable, and that the management structure is (or has been made) adequate to control costs" (Nunn-McCurdy Act, 1982).

procurement costs of the radios. Whereas previous JTRS contracts called for the delivery of fixed quantities, the JPEO issued (IDIQ) contracts to procure CSCHR. These contracts are used when the issuing agency cannot determine (above a specified minimum) the number of units needed. By issuing a single IDIQ contract, the JPEO fostered competition, which, in turn, drove down production costs.

In 2008 the JPEO changed CISCHR to CSCHR. Removing “interim” from the program’s title is, perhaps, indicative of its more permanent status within the JTRS family. According to the JPEO, “the goal is to give the [CSCHR] program the means to adapt to technological innovation over a longer period and allow companies to better leverage their investment” (Baddeley, 2010, p. 2). In any case, had the JTRS program initially adopted an evolutionary acquisition approach, it is likely that the CSCHR would have entered production some years ago. Jim White, the JPEO CSCHR Product Manager, notes that this acquisition process “may not have everything they need today, but it certainly can be enhanced to add that capability over time” (Baddeley, 2010, p. 2). He went on to say that these competitions “aimed to help the services procure the best product at the best price, within the specifications they defined” (Baddeley, 2010, p. 10). Over time, the JPEO plans to invite other vendors to compete, provided that they adhere to the same standards.

Currently, CSCHRs are the only widely fielded radios to come out of the JPEO. As of June 2010, more than 125,000 Harris AN/PRC-152 radios have been fielded, and 75,000 Thales JTRS-Enhanced Multiband Inter/Intra Team Radio (JEM) units (see Figure 14). Since they are not multi-channel, these radios are only “JTRS approved” as opposed to “JTRS certified.” However, the CSCHRs support new JTRS waveforms (with the exception of the WNW) and their procurement may be more cost-effective in the near-term. For instance, the JEM can make use of the legacy Multiband Inter/Intra Team Radio system elements, accessories, and ancillaries. In addition, since the JTRS version is software-defined, it can accept new encryption schemes as they become available. Finally, the JEM’s interface is similar to the legacy MBITR, allowing warfighters trained with one radio to switch to the other rapidly (Baddeley, 2010).

Figure 14. The CSCHR Program Includes the Thales JTRS-Enhanced Multiband Inter /Intra Team Radio (JEM) (left) and the Harris AN/PRC-152 (right)
(Keller, 2011; Harris Corporation, 2005)

V. Lessons Learned

Upfront Systems Engineering is Critical

It is not clear if the true transformational capabilities of the JTRS program were appreciated at the program's inception. Even the name of the program would lead one to believe that it is but another tactical radio program. JTRS would impact many aspects of the battlefield by providing networked communications, enabling true, secure, connectivity across organizations and echelons. JTRS would not only improve information sharing, but has the potential to improve the quality of the information shared. This, in turn, would lead to improved situational awareness, enabling collaboration and self-synchronization, and enhancing the speed of command. As a result, JTRS would have wide-ranging impact, from platforms, to organizational structures, training, tactics, and doctrine. From a technical perspective, it was critical to understand how the different elements of the program would interact, to ensure the optimal level of integration and interoperability.

The complex nature of the JTRS program development presented a prominent challenge to the integration effort. When developing a single system, tradeoffs between system attributes may have to be considered. However, when dealing with a complex, enterprise-wide system of systems, such as JTRS, decisions made about individual components or systems will have ripple effects on the other elements within the system. Consequently, initial systems engineering and planning is critical to ensure that both the appropriate allocation of capabilities and requirements to individual elements is made, and that the purpose of these individual elements and their relationship with other elements within the system are fully understood. This initial systems engineering also enables the identification of any gaps that exist in technology, software, and engineering capabilities.

Although JTRS was conceived as an enterprise-wide communication infrastructure, the original organizational structure of the program, unfortunately, did not have a strong enterprise system focus, and instead, created service equities. The JTRS funding was programmed through the services, with service-centric program reporting. As a result, there was no advocate for the enterprise capabilities, and consequently, little effort was expended to develop a systems engineering master plan; accordingly, not enough detail was available for how a certain radio, waveform, or other components were to be developed. In the end, contracts were written that did not adequately specify how the individual products were going to be tested, or how they were to be integrated with other elements into the overall network. As Deputy PEO Colonel Ray Jones asserted, “you can’t put generalities [in contracts] and expect the contractors to pull the radio out of a hat. That’s what I think we did as a department. We didn’t do our homework” (personal communication, July 5, 2011). As a result, JTRS had many technical and programmatic difficulties that required a major organizational restructuring.

The lack of upfront systems engineering also precluded an adequate assessment of platform integration. Often, the physical configuration and technical requirements of specific platforms were not adequately considered during the initial design phases; in some instances, it was unclear as to which platforms would even carry JTRS radios. Consider the case of the Bradley Fighting Vehicle whose Operational Requirements Document (ORD) specifies that all integrated systems must be rated up to 71 degrees Celsius (approximately 160 degrees Fahrenheit). The GMR, however, was designed to operate up to a maximum temperature of 55 degrees Celsius. In addition, the physical dimensions of the GMR were such that it could not be easily installed in the vehicles. In the end, it was decided that the GMR would not be installed in the Bradley.

It appears that the platform given the most thorough consideration during the GMR design phase was the Manned Ground Vehicle, a component of the cancelled FCS program. Curiously, the FCS program, if realized, would have comprised only a fraction of the Army’s combat brigades, the majority of which rely on the M1 Abrams tank and the Bradley. It is unclear why the configurations of these platforms were not given greater consideration.

The lack of upfront systems engineering has also engendered conflict between the services and the JPEO. For instance, some industry experts have questioned the wisdom of developing a JTRS version of MIDS-LVT, and have proposed that an altogether new JTRS radio be developed for those aircraft that currently rely on the older system (Erwin, 2003). However, the primary users of MIDS, the Air Force and the Navy, are quite adamant in their demand that the JPEO continue to develop MIDS-JTRS—a system that will "form fit" the space and weight of the older MIDS version—in an effort to save time and money. The Navy, which initiated development of MIDS-JTRS when the radio was part of the Cluster 3 program, has no intention of altering the interfaces of its aircraft to accommodate non-MIDS JTRS (Erwin, 2003). Because the services were free to procure their own JTRS radios prior to the program's restructuring, there was little thought with regard to how MIDS would be integrated into the JTRS network. One might say that developing a MIDS-JTRS is tantamount to upgrading a decade-old cellular flip phone with smart phone technology. In this case, one might as well just buy a new phone. As mentioned earlier, technical problems have delayed the program and increased costs, prompting a decrease in demand among the services. The program was suspended in 2007 pending a determination as to whether there were enough potential users to support further development.

In summary, the lack of adequate, upfront systems engineering made well-informed trades between user requirements and available resources difficult to see or make. As a result, program cost and schedule targets were made based on available, and generally inadequate, information. As the program progressed, problems that were discovered resulted in schedule delays and the need for more funding than had been estimated at program launch.

Leverage the Advantages of Competition

By fostering competition, the DoD was able to drive down the cost of acquiring Consolidated Single Channel Handheld Radios (CSCHR). The CSCHR acquisition strategy stands in stark contrast to the strategy used to develop and procure other JTRS variants. First and foremost, the competition among vendors was full and open. In addition, a separate contract was issued for pre-system design and development; this was not the case with other variants. For instance, in the case of the GMR, the contract was inclusive of all stages of development and production, with a scheduled duration of six years. The CSCHR contract, on the other hand, was written in the form of a one-year agreement with extension options, thereby incentivizing contractor efficiency. Whereas previous JTRS contracts called for the delivery of fixed quantities, JPEO issued an Indefinite Demand/Indefinite Quantity (IDIQ) contract to procure CSCHR. The contract also allowed for the addition of technology insertion clauses, providing vendors with the opportunity to submit solutions to the JPEO for consideration. If the JPEO found that the solution would benefit the warfighter, it was then added to the contract. As such, the contract explicitly promoted and facilitated incremental development.

It is unclear how the fielding of CSCHRs will impact the development and production of “true” JTRS handheld radios (e.g., JTRS HMS). While CSCHRs are certainly an improvement over existing legacy radios, and, more important, they are available to warfighters now, it is possible that their fielding will reduce demand for, and delay the production of, HMS. If this occurs, then the multi-mode networking capabilities allowing for seamless communication among all Armed Forces entities—in short, the JTRS vision—will remain unrealized. At the same time, however, it appears that the recent gains in efficiency realized by the HMS program (illustrated in Figure 8 of the previous section) coincide with the production and fielding of CSCHR. The JPEO’s use of a competitive acquisition strategy promoted competition within the CSCHR program; it is likely also promoting competition between JTRS programs.

Use an Evolutionary Acquisition Strategy

The JTRS program did not use an evolutionary strategy, an approach based on the rapid incremental development of systems using mature technologies. Consequently, all of the system’s requirements specified in the Operational Requirements Document (ORD) had to be met prior to initial fielding. These requirements, then, included the demonstration of waveforms that had yet to be fully developed. The concurrent development of hardware and software posed (and continues to pose) a challenge that is discussed at length in the next section. Suffice it say that delaying the program, in anticipation of the release of these waveforms, resulted in significant cost increases.

Perhaps this evolutionary approach is understandable when one considers the program’s fundamental attribute: functional versatility (i.e., the ability to enhance the system by adding new software functionality at minimal effort and expense). As discussed earlier, the JTRS hardware must be sufficiently versatile so as to be compatible with future software applications. Indeed, the JTRS vision explicitly calls for the progressively more sophisticated, incremental development of waveforms; the hardware, on the other hand, is to be the mainstay of the program. Accordingly, the pressure to—with regard to the hardware—“get it right the first time,” undoubtedly delayed the manufacture and procurement of the radios, possibly for good reason. JTRS personnel are increasingly finding that many traditional hardware functions (e.g., antennas, power amplifiers, oscillators, passive filters, and power supplies) are simply not “software implementable,” thus requiring the development of new radios, or at a minimum, upgrades to existing ones (Lipets, 2008). Moreover, the release of advanced, high bandwidth waveforms that prove incompatible with the existing hardware, may pose a problem. But delaying procurement cuts both ways. Without an evolutionary approach, by the time the product is ready for production, the “next best thing” has already taken root in developers’ minds, hastening its obsolescence. Adopting an evolutionary approach whereby a basic capability is fielded, and incremental capability improvements are periodically made in subsequent blocks, can actually mitigate risk in the long-run. By shortening development timetables and ensuring the use of mature technologies, such an approach would reduce the risk of program delay and cost overruns.

An evolutionary approach also ensures that operational experience informs future versions of a product’s requirements. In the case of the GMR, for example, the failure to pursue an evolutionary approach has made it difficult to incorporate user criticism into the radio’s design. In its 2011 evaluation of several network components, the Army stated that “GMR is neither simple nor easy to operate” and that the system’s display screen “was not intuitive for soldiers to use” (Brannen, 2011, p. 1). That JPEO is encouraging SPAWAR to investigate commercial alternatives to the GMR may indicate that it is questioning the radio’s viability. In any case, it is clear that the comments and suggestions by end users of the GMR are important to fielding an effective system. The adoption of an evolutionary strategy may have identified these problems earlier.

The CSCHR is an example of a product that, in all likelihood, could have been procured earlier had the DoD adopted an evolutionary approach initially. And as mentioned earlier, all four of the services, in their initial objections to the JTRS program, cited the need for near-term solutions. Indeed, adoption of an evolutionary approach might have obviated the need to purchase legacy radios to equip troops in Iraq and Afghanistan, while paving the way for the more rapid fielding of HMS. In this way, the program could have fielded essential technologies in the near-term, by delaying the instantiation of more time-intensive, costly, or technically challenging capabilities. A successful evolutionary approach, however, depends on adequate upfront systems engineering, which, as was discussed previously, was not done. Although an evolutionary approach is both designed and undertaken to allow operational experience to inform future product requirements, the addition, over time, of basic capabilities is determined well in advance.

It seems clear enough that frontloading all of the capabilities, many of which are untested or immature, onto a product is unwise. In the private sector, progressively more sophisticated versions of, say, the iPhone are released by Apple in response to near-continuous consumer demand. On the other hand, within the DoD there is often significant pressure to provide the troops with the best capability. The irony is that a significant period of time passes during which nothing new is fielded. This pressure, it seems, is often felt throughout the enterprise. Vice Chief of Staff of the U.S. Army, Peter Chiarelli, for instance, notes how "struck" he was that JTRS engineers were worried about a 10 second latency in a certain JTRS radio, noting that large programs are often out of touch with the needs of warfighters (Erwin, 2010). He reasoned that, "if I don't have that radio, troops have to go up a mountain to get line of sight and expose themselves to enemy fire. They'd much rather have a 10 second latency that allows them to remain concealed" (Erwin, 2010, p. 23).

The Acceptance of SCA as a Commercial Standard Provides Significant Benefits

The foundation for the JTRS family of radios is the SCA. It is simultaneously an architecture framework, specification, and guidance document for software-defined radios, allowing convenient reuse, update, or replacement of software. The goals of the SCA specification include reducing the development expense by reducing the development time through reusing existing components. The overall objective is to guarantee the portability of software so as to be able to reconfigure hardware platforms. The success of SCA can be, in part, attributed to its acceptance as a commercial standard. SCA is now the de facto standard for all software-defined radios; it has been endorsed by the Software Defined Radio Forum and the Object Management Group, both well-known standards bodies.

This was not preordained. The DoD tried this strategy before, with the development of the programming language Ada (to be used for embedded systems). The DoD adopted a series of policies to encourage adoption of Ada as the standard that applied to increasingly broader programming domains. Ada became mandatory for all DoD software, except when a special waiver was granted. However, despite these efforts, Ada was never adopted as a commercial standard, and since the commercial market dwarfed the military market, it eventually fell out of use, even within the DoD except for some very limited applications (Chapin, 2004).

With the wide acceptance of the SCA standard, the DoD will be able to leverage the commercial development of programming environments and tools. This will, in turn, reduce future development costs and foster a more competitive environment; all significant benefits.

An Open Systems Architecture Does Not Obviate the Need for Planning

In response to a GAO recommendation to delineate the limitations of commercial and DoD technology "in satisfying current and future JTRS requirements," the DoD asserted that "[JTRS'] open systems architecture is responsive by nature to changes in technology and is flexible in design to accommodate technological advances in software and hardware" (GAO, 1999, p. 29). Although this may be true in theory, there is some work that needs to be done to integrate specific applications. For instance, video from Unmanned Aerial Vehicles (UAVs) sent over Common Data Link (CDL) waveforms can be viewed currently only with the use of a Rover or Video Scout computer which, in turn, feeds the output into the JTRS radio via a plug-in device (Button, 2010). This means soldiers have to carry additional hardware, thereby defeating one of the very reasons for which JTRS was conceived, while adding significant operating costs.

Although the DoD had mandated that the CDL waveform be used for viewing video prior to the JTRS program's inception, it was not envisioned to be an initial JTRS required capability because it was outside the required frequency range. Currently, the DoD is funding research for the development of a "workaround" to add UAV video viewing capabilities to JTRS (Button, 2010, p. 1). A JTRS spokesman explained that the JPEO never considered adding the CDL waveforms to the JTRS repertoire because their use required excessive bandwidth (JTRS waveforms use frequencies between 2 megahertz and 2 gigahertz; the CDL is a higher frequency waveform, operating above 2 gigahertz). At the same time, the JTRS program had always planned to develop and acquire waveforms “above 2 GHz” at some point in the future (Baddeley, 2005).

The porting of high-bandwidth waveforms (i.e., those operating above 2 GHz) onto JTRS radios constitutes a significant challenge, especially with regard to hardware design (Davis & Aslam-Mir, 2008). Designers are finding that they must, in effect, compensate for the limited guidance provided by the SCA (originally applicable to waveforms operating at frequencies from 2 megahertz to 2 gigahertz) by developing hardware solutions. Clearly, then, the JTRS architecture’s flexibility and responsiveness have limits.

As for the SCA’s capacity to accommodate higher frequency waveforms, only time will tell. Recent efforts, including the Air Force’s High Data Rate-Radio Frequency (HDR-RF) Modem program, which has experienced a number of challenges, “have served to highlight how the SCA specification needs enhancement to provide guidance to the designers of such platforms” (Davis & Aslam-Mir, 2008). Currently, an enhanced version of the SCA (version 3.0) is under development.

One might argue that oversights of this sort are unavoidable. It could be that future communications challenges are simply too difficult to anticipate. With the continued, rapid innovation of information technologies, it may be that even today’s most versatile hardware platforms will be incompatible with the software innovations of tomorrow. Nevertheless, it is likely that better upfront planning would have mitigated some of these challenges.

Concurrent Development can be Problematic

The concurrent development of waveforms and radios contributed significantly to the challenges and setbacks that the JTRS program has encountered since its inception. Program officials underestimated the complexity of the technology involved, leading them to believe that the SCA would be sufficient to adequately convey JTRS specifications to program personnel and government contractors. This assumption proved faulty, and contractors developed their systems based on their interpretations.

Revisiting the analogy between JTRS and Microsoft Word helps to illustrate the problem. While PC and Mac users are both able to run Microsoft Word, they require versions of the program that are specific to their operating systems; one cannot run the PC version of Word on his or her Mac computer. In the end, contracts with these general specifications resulted in hardware and software that were incompatible.

Furthermore, any unforeseen challenges with regard to the technical implementation of certain components—and there were several—exacerbated this problem. Where were such challenges to be addressed—in the radio or in the waveform? The Network Enterprise Domain, responsible for waveform design, assumed that the radio contractors would address certain problems, and vice versa. This assumption was further aggravated by the pace of the program; if it takes 36–48 months to develop the hardware and/or software, the open system standards have likely been updated several times. According to Colonel Ray Jones, JTRS Deputy PEO, the majority of delays and cost increases within the enterprise were the direct result of unmet expectations on the part of the radio design contractors; in other words, the waveforms provided did not meet the design expectations of the contractors, each of which plugged unspecified technical gaps with unique hardware solutions or failed to address them altogether.

Inadequate Process Alignment Leads to Inefficiencies

Processes misalignment has led to cost overruns and delays. Even within the Airborne, Maritime, and Fixed Site (AMF) program, which, by some accounts, has been the most successful in meeting its budget and deadlines, there has been trouble aligning various processes. After several years of development, the program had developed a four-channel, full duplex, software-defined radio to be integrated in airborne, shipboard, and fixed-station platforms; providing data, voice, and networking capabilities through implementation of five initial waveforms. The radio had successfully navigated through Preliminary Design Review (PDR)—the government's assessment of the progress, technical adequacy, and risk resolution of the selected design approach—and successfully completed its Milestone B in September of 2009, authorizing its entry into the Engineering and Manufacturing Development phase. Shortly thereafter, the NSA contacted the JPEO to inform the AMF program manager that the AMF design was not certifiable, and that the program had not, in fact, completed its PDR. The program manager stated that the DoD had signed off on PDR, but that any design deficiencies with regard to cryptography would be addressed during the next phase (i.e., at the Critical Design Review [CDR]). The NSA objected, asserting that NSA certification was essential to the successful completion of PDR.

Apart from some semantic disagreements, it appeared—at least at first glance—that the NSA's insistence would be of little consequence: the program could simply revert to the pre-PDR development stage, make the changes, and then resume pre-CDR development. However, once Lockheed Martin, the AMF program's lead contractor, was informed that the necessary modifications fell under the purview of the PDR, Lockheed Martin asserted that any additional work was out-of-scope. The AMF program manager contended, however, that the contract specified delivery of a certified radio and that the contractor had failed to meet an integral requirement. The question became, what is a certified radio, and who is responsible for issuing the certification? The two parties disagreed on the answer, for obvious reasons, and engaged their lawyers. In the end, the contractors were able to convince the program official that the work was, indeed, out-of-scope. The program was pushed back by several months, requiring additional funding for the contract change order.

The system of checks and balances that is built into the acquisition cycle, while necessary, often gives voice to existing organizational and cultural inertia and biases. Individual stakeholders—from contractors and services' representatives, to program personnel, functional experts, and testers, may often have objectives that are not completely aligned with those of the program's, whose focus is on the successful delivery of a final product to its users.

This is not to suggest that these stakeholders are not working to field the required capability; rather, it is a symptom of a misaligned process whereby various stakeholders may have different objectives. Take, for example, the case of the JTRS-certified, NSA certified, SCA compliant AN/PRC 117G radio manufactured by Harris. The JPEO promoted this commercial radio as an available, near-term solution to the Army's radio communication needs. Like the hand-held CSCHR, the 117G Manpack, while not a DoD product, offers many JTRS capabilities, including the capacity to port five legacy waveforms and the Soldier Radio Waveform that is being developed for JTRS by NED. The 117G is not, however, compatible with the Wideband Networking Waveform. Many within the DoD acquisition hierarchy objected to its fielding, preferring to wait until JTRS radios could be procured. Colonel Ray Jones noted that there were “many who took pride in having had nothing to do with the purchase of this radio ... despite the fact that it is currently in theatre making a difference and saving lives” (personal communication, August 1, 2011). Within the DoD, and despite official pronouncements, it seems that there is no consensus with regard to either the adoption of an evolutionary process or the purchase of commercial products.

Governance Structure is Important

As discussed previously, the original clusters approach lacked a cohesive enterprise perspective and led to decentralized program execution. The result was a program that was not achieving the overall program objectives, and led to significant cost increases. In order to successfully control costs, oversee the creation of a systems engineering Master Plan, ensure process alignment, and implement an enterprise-wide evolutionary approach to acquisition, a central authority must be established prior to the launch of the program. The JPEO has had success in these three areas, but the program as a whole continues to experience problems stemming from the initial approach.

VI. The Way Forward

The services' demand for JTRS radios has decreased sharply in recent years. Demand for ground radios, namely the Ground Mobile Radio and Handheld, Manpack, and Small Form Fit radios, has been hit the hardest. In terms of delays, cost increases, technical difficulties, and predicted capability, these two programs have, unsurprisingly, encountered the most serious problems. Between 2004 and 2007, the Army reduced its planned purchase of GMR radios by 19%, the Air Force by 89%, and the Marines by 91% (CBO, 2009). Over the same period, the Air Force reduced its HMS estimate by 52%, the Army by 66%, the Marines by 68%, and the Navy by 72% (CBO, 2009). However, nearly half of the initial decrease in demand for HMS radios can be attributed to U.S. Special Operations Command, which opted out of the JTRS program in 2009. In September of the same year, the Air Force and Navy announced plans to cancel their JTRS contracts entirely. Ironically, it seemed, for a short while, that JTRS might revert to an Army program. The Army announced its plan to fund 80% of the entire JTRS program and purchase 95% of all JTRS radios through 2026.

During the summer of 2011, Army combat units tested a number of JTRS components at the White Sands evaluation facility in New Mexico. In an effort to understand how well the technology would function in real-world contexts, warfighters equipped with JTRS radios engaged in various combat simulations. In addition to taking note of any technical deficits that might surface, program officials wanted to observe how the warfighters actually used the new technology at their disposal. They found, perhaps unsurprisingly, that the users were not taking full advantage of the transformational networked communications capabilities that JTRS offered. In fact, according to Colonel Ray Jones, they were assimilating the new technology into existing operational contexts appropriate to the given combat simulation, the majority of which were centered on relaying information hierarchically (e.g., from the company to the battalion to the brigade).

The tenets of net-centric warfare that have guided development of the JTRS program have been propounded repeatedly by scholars, the DoD, and industry. Nevertheless, it is easy to forget, amidst all of the technical complexity, the requisite human element that will make the JTRS vision a reality. Indeed, the development and practical implementation of a net-centric operational context may still be behind its technical advent; the numerous schedule setbacks and cost overruns notwithstanding. The successful integration of software and hardware is merely the first step in assimilating the JTRS vision into military operations of tomorrow.

Of course, the teaching and learning component of JTRS-enabled netcentricity must, to some extent, follow its technical implementation. Certain base components must be sufficiently evolved so as to be of use. However, it is not until user feedback regularly informs subsequent technical development that the JTRS vision will be fully realized. The pace of technological innovation in the commercial market bears this out. The accelerating rate at which new personal computers, Smart phones, and MP3 players appear on store shelves is as much a function of new technology (creating the demand for new capabilities), as it is the accumulation by industry of users' feedback and desires.

Once the two processes—user input and technological innovation—merge, as is the case within the private sector, an uninterrupted loop spurs ever increasing gains in efficiency and performance. As a result of these gains, potential users throughout the DoD will seek to take advantage of JTRS, which will increase its value. According to Metcalfe's Law—a phenomenon that is well known in computer science circles—the value of a communications network is proportional to the square of the number of connected users of the system. This law has often been illustrated using the example of fax machines: a single fax machine is useless, but the value of every fax machine increases with the total number of fax machines in the network because the total number of people with whom each user may send and receive documents increases (Tongia & Wilson, 2010).

And while this process may appear organic—and to an extent it is—one should not underestimate the need to educate and train the users so that they can fully exploit the benefits that JTRS offers. Indeed, one of the major challenges of the future will be the mapping of a trajectory along which the program can grow and evolve. On the one hand, this process will require that user feedback be collected and analyzed. Accordingly, the constraints imposed on users with regard to appropriate use must not stifle the program's growth. At the same time, firm protocols must direct this growth so that the communication capability provided by JTRS does not become a liability but, instead, enables emergent behaviors.

As the U.S. economy, still reeling from the recession of 2008, continues along the path to recovery, lawmakers are searching for ways to cut spending in order to reduce the country's $14.5 trillion debt. Congress has not yet developed a strategy to manage growing entitlement spending. Accordingly, the DoD, which consumes the second largest portion of government revenue after entitlements, will likely see significant cuts in coming years. Indeed, cuts are already being made. In August 2011 Congress reached a budget deal that aimed two axes at the DoD. The first was a $350 billion cut in defense spending over the next 10 years. The second was the threat of some $600 billion more in cuts which would automatically be triggered in the event that a special congressional committee fails to agree on future deficit reductions. As top military leaders confront budgetary constraints, it seems likely that the DoD investment in technologies for which a commercial market exists will decline significantly. This seems especially true of JTRS. Given the sharp decrease in demand among the services for DoD-manufactured JTRS radios, and the resulting per unit cost increase, the user community may need to look to the commercial sector to fill their radio communications requirements.

Recommendations

We make the following recommendations based on the lessons learned from the JTRS program. These recommendations are applicable to the development, acquisition, and fielding of other large-scale, enterprise-wide military systems.

1. Lay a foundation for success

- **Centralize program governance**

  In order to successfully control costs, oversee the creation of a systems engineering Master Plan, ensure process alignment, and implement an enterprise-wide evolutionary approach to acquisition, a central authority must be established prior to the launch of the program.

- **Insist on thorough, upfront systems engineering**

  It is imperative that an enterprise-wide systems engineering master plan be developed prior to the development of a large-scale, complex system. The functional decomposition must be detailed enough so that the performance of the individual elements can be adequately specified. It is not enough to assume that a general architecture description will be able to provide the requisite detail for contractors to develop interoperable systems. Upfront systems engineering need not impede a system's technical evolution, but, on the contrary, should enable it.

- **Use history as a guide**

  Planners often focus on the most optimistic scenario with regard to the task at hand rather than using their full knowledge and experience of how much time similar, past tasks required. This is known as the planning fallacy, first proposed by psychologists Daniel Kahneman and Amos Tversky in 1979. Dan Lovallo and Daniel Kahneman (2003) proposed an expanded definition, according to which the tendency to underestimate the time, costs, and risks of future actions coincided with the over-estimation of the benefits of the same actions. According to this definition, the planning fallacy often results in not only schedule delays, but also cost overruns and performance shortfalls.

  In this case, the JTRS predecessor, the SPEAKeasy radios, were of limited value because wideband waveform capability, reprogrammable cryptology, and multi-channel operation were never implemented because of unforeseen cost increases and technical difficulties. JTRS has faced these same three challenges: JTRS has struggled to meet size and weight constraints imposed by the wideband waveform, the NSA certification process has hindered the fielding of JTRS, and single-channel JTRS-approved radios are the only variants that have been widely fielded. It is not that the challenges associated with SPEAKeasy were unknown to JTRS developers; rather, they believed that this time would be different.

- **Align the various processes within the acquisition hierarchy**

  The processes within the DoD acquisition process must be aligned with the end game. Realization of the Master Plan should be the driving motivation behind every entity within the hierarchy. Individual stakeholders—from contractors and services' representatives, to program personnel and product testers—should all be accountable for the delivery of a final product to its users. A product tester, for instance, must be incentivized to not only uncover the deficits of a product or the technical oversights within a program, but he or she must also be accountable for communicating these issues to program management in a succinct and timely fashion. More important, the tester should articulate how such deficits impact not only the product in question, but the enterprise as a whole. Every step of the way, the question should be asked, is this process or organization within the hierarchy really set up to speed capabilities to the warfighter?

2. Ensure program gets off to a good start

- **Use an evolutionary acquisition strategy**

  An evolutionary approach helps to ensure the rapid deployment of systems. When systems are developed incrementally, based on mature technology, the program risk is minimized. As a result, delays in development are reduced, helping to keep pace with the software development cycle and keep cost growth in check. Evolutionary development is also advantageous in that it allows for changing requirements.

  To effectively implement an evolutionary strategy, users must allow more flexibility with their requirements so that developers can make the needed cost, performance, and schedule trade-offs, deferring some requirements to later releases. These revisions may change the outcome of a specific increment, but not that of the final required capability. Current DoD programs do not generally demonstrate this adaptability until budget overruns require action. Users must also trust that the programs will continue as planned, and be willing to accept less capable systems earlier (i.e., the "80% solution"), and then evolve to the desired capability in later increments.

Had the JTRS program relied on an evolutionary approach early on, it is likely that the services would possess more and better communications capabilities than they do currently.

- **Maximize the benefits of competition during all program phases**

Competition, built in from the beginning of acquisition planning, is critical to ensure that its benefits can be harnessed throughout the process. Because of the current phased design and development requirements for system acquisition, natural cutoff points exist for competition to be introduced into the process. Early on in the JTRS program, the JPO awarded Boeing a contract in the amount of $856 million for the development, demonstration, and low-rate initial production of 10,000 JTRS Cluster 1 units. Rather than awarding one large contract, the program could have had competitions at the program phase points, including production. Competition during production, however, is often resisted, even though it is the key to ensuring a real incentive is given for contractors to ensure that they meet cost, schedule, and performance requirements.

With the procurement of the CSCHRs, the JPEO was able to avoid severe cost overruns by issuing more flexible contracts. The IDIQ contracts that were issued allowed the precise number of radios produced by the vendor to go unspecified. Accordingly, the DoD had the option of procuring similar products from other vendors. This possibility spurs competition, which reduces costs. Today, CSCHR are the only widely fielded radios to come out of the JTRS program.

3. Execute program using proven practices

- **Fund DoD programs at the enterprise level**

In an effort to better align the processes within the acquisition hierarchy, JTRS, and other large, enterprise-wide programs, should be funded at the enterprise level. This will allow executives to allocate and divert funding based on a program's progress in meeting its objectives. If one program is struggling to contain costs or is encountering technical challenges, funding can be cut off or added at the discretion of management.

- **Effectively communicate objectives to all program stakeholders**

  The JTRS program has suffered an identity crisis since its inception. Though never officially billed as a radio replacement program, the transformative capabilities of a networked communications system are often still not well understood. DoD officials have found that warfighters are not taking full advantage of the transformational networked communications capabilities that JTRS offers. In fact, they are assimilating the new technology into existing operational contexts, the majority of which were centered on relaying information hierarchically. Recognizing these shortcomings, the program is establishing training protocols.

Conclusion

The innovation of IT systems continues at an extremely rapid rate. One worry is that the current DoD acquisition system lacks the agility inherent in the commercial sector to keep pace. Once texting became popular, for example, developers began to manufacture phones with full keyboards. They were able to do this in relatively short order because private industry is, by its very nature, acutely responsive to customer demand, creative in its solutions, and driven to maximize efficiency.

In biology, gradualism—the theory that evolution occurs uniformly by steady transformation—is often contrasted against punctuated equilibrium, according to which species will exhibit little evolutionary change for most of their geological history. When significant evolutionary change does occur, the theory asserts that it is restricted to rare and rapid events of speciation. These two theories track closely to innovation and product development, where both types of evolution occur. In fact, the emergence of truly transformative innovation seems to occur most readily within an environment that facilitates the gradual refinement of products. It seems clear that the DoD acquisition system must be reformed to both adjust to constantly evolving technologies, as well as those disruptive technologies (call them "speciation" events), which bring about significant change. The advent of SDR was itself a disruptive technology that the DoD embraced early on; it must now seek to emulate the gradualism seen in the commercial sector in order to refine and improve the JTRS program in a timely, cost-effective way.

At present, the software-defined radio has a lot of momentum behind it—and not just from potential military applications. Improvements and additions to software-defined radio technology are common, from radio systems manufacturers like Harris RF Communications, Thales, and Rockwell Collins, to embedded signal processing specialists like Pentek, TEK Microsystems, and Nallatech, to real time software providers like Green Hills and Lynux Works. Furthermore, September 11, 2001 demonstrated that domestic first responders have some of the same challenges with communications interoperability as the U.S. military and its allies do. These first responders, civil transportation, and even private communications stand to benefit from advances in SDR technology. Nearly everything that U.S. military forces need in software-defined radio capability is available, or emerging, in the commercial sector. The increased demand for JTRS-like systems will undoubtedly contribute to further commercial investment, leading to new innovations while at the same time driving down costs. The DoD must continue to leverage development in the commercial sector in order to provide the best capability to our military forces while reducing development costs.

The DoD intended to shift to commercial off-the-shelf (COTS) technology back in the early 1990s in an effort to harvest the best technologies from the private sector rather than develop its own, which often resulted in re-inventing the wheel. The increased emphasis on SDR technology by the commercial sector will likely convince the DoD to fully embrace its COTS initiative. None of this is to suggest that the JTRS program has failed or that the DoD should never have become involved in the development of SDR technology. In retrospect, it might be easy to say that the military should have waited for industry to provide the necessary technology; that instead of investing tens of billions of dollars in military radios, it should have purchased COTS products from private-market vendors. But the question is how long would the military have needed to wait? DoD helped to shape the commercial development of SDR and helped to ensure that it would be compatible with military requirements. Today's commercial market SDRs all rely on the Software Communications Architecture, the development of which was funded by the military. The same can be said with regard to waveform development. The DoD's initial investment spurred the commercial sector growth of SDR. In fact, many of today's vendors were subcontractors for JTRS that later decided to develop their own radios with the hope of competing them to meet anticipated demand.

In addressing the Subcommittee on Tactical Air and Land Forces, General Peter Chiarelli, Vice Chief of Staff of the U.S. Army, made the following statement:

> Today, the Army is past talking concepts. We are making the Network happen, delivering needed capability downrange as we speak. That said, there is still much to be done. In particular, we are very focused on doing everything we can to get more network capability into theatre— faster. (*Statement by General Peter W. Chiarelli*, 2011, p. 8–9)

Some critics have remarked that JTRS is in danger of being canceled. Such musings betray a lack of understanding of the DoD's commitment to the program. There is but one architecture, and it has been endorsed by the commercial sector. Even if JTRS programs are canceled, there is no question that their equivalents will emerge eventually in the form of rebranded DoD programs or commercially produced products. Thus, the question is not so much where the DoD is going with regard to its future communication system, but how it is going to get there. Continuing to build partnerships between private industry and the DoD is certainly part of the answer. Furthermore, incremental development, better process alignment, and increased accountability can be implemented to hasten, in a cost-effective manner, the realization of the JTRS vision.

Given the current budgetary environment and the increased political pressure to reduce defense spending, the DoD must improve the efficiency with which it develops, acquires, and fields large-scale, enterprise-wide systems, such as JTRS. But even in the absence of such pressure, the DoD has a responsibility to the taxpayers to improve its capabilities at a reasonable cost. Most important, every effort should be made to equip the men and women in uniform with cutting edge, indeed lifesaving, technology so that they are able to carry out their missions successfully. This must be done in a timely, efficient manner. They deserve nothing less.

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About the Authors

Jacques S. Gansler

The Honorable Jacques S. Gansler, former Under Secretary of Defense for Acquisition, Technology, and Logistics, is a Professor and holds the Roger C. Lipitz Chair in Public Policy and Private Enterprise in the School of Public Policy, University of Maryland; he is also the Director of the Center for Public Policy and Private Enterprise. As the third-ranking civilian at the Pentagon from 1997 to 2001, Dr. Gansler was responsible for all research and development, acquisition reform, logistics, advance technology, environmental security, defense industry, and numerous other security programs. Before joining the Clinton Administration, Dr. Gansler held a variety of positions in government and the private sector, including Deputy Assistant Secretary of Defense (Material Acquisition), Assistant Director of Defense Research and Engineering (electronics), Executive Vice President at TASC, Vice President of ITT, and engineering and management positions with Singer and Raytheon Corporations.

Throughout his career, Dr. Gansler has written, published, testified, and taught on subjects related to his work. He is the author of five books and over 100 articles. His most recent book is *Democracy's Arsenal: Creating a 21st Century Defense Industry* (MIT Press, 2011).

In 2007, Dr. Gansler served as the Chair of the Secretary of the Army's "Commission on Contracting and Program Management for Army Expeditionary Forces." He is a member of of the Defense Science Board and the Government Accountability Office (GAO) Advisory Board. He is also a member of the National Academy of Engineering and a Fellow of the National Academy of Public Administration. Additionally, he is the Glenn L. Martin Institute Fellow of Engineering at the A. James Clarke School of Engineering, an Affiliate Faculty member at the Robert H. Smith School of Business, and a Senior Fellow at the James MacGregor Burns Academy of Leadership (all at the University of Maryland). From 2003–2004, he served as Interim Dean of the School of Public Policy at the University of Maryland and from 2004–2006, Dr. Gansler served as the Vice President for Research at the University of Maryland.

William Lucyshyn

William Lucyshyn is the Director of Research and a Senior Research Scholar at the Center for Public Policy and Private Enterprise in the School of Public Policy at the University of Maryland. In this position, he directs research on critical policy issues related to the increasingly complex problems associated with improving public-sector management and operations and with how government works with private enterprise.

His current projects include modernizing government supply-chain management, identifying government sourcing and acquisition best practices, and analyzing Department of Defense business modernization and transformation. Previously, Mr. Lucyshyn served as a program manager and the principal technical advisor to the Director of the Defense Advanced Research Projects Agency (DARPA) on the identification, selection, research, development, and prototype production of advanced technology projects.

Prior to joining DARPA, Mr. Lucyshyn completed a 25-year career in the U.S. Air Force. Mr. Lucyshyn received his bachelor's degree in engineering science from the City University of New York and earned his master's degree in nuclear engineering from the Air Force Institute of Technology. He has authored numerous reports, book chapters, and journal articles.

John Rigilano

John Rigilano is a Faculty Research Assistant at the Center for Public Policy and Private Enterprise. He earned his master's of public policy degree from the University of Maryland, College Park in 2011, and holds a Bachelor of Arts degree in anthropology from the Pennsylvania State University. He is pursuing a career in policy and program analysis.

The Center for Public Policy and Private Enterprise provides the strategic linkage between the public and private sector to develop and improve solutions to increasingly complex problems associated with the delivery of public services — a responsibility increasingly shared by both sectors. Operating at the nexus of public and private interests, the Center researches, develops, and promotes best practices; develops policy recommendations; and strives to influence senior decision-makers toward improved government and industry results. The Center for Public Policy and Private Enterprise is a research Center within the University of Maryland's School of Public Policy.

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