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Lessons from the Army's Future Combat Systems Program

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Preface

The Future Combat Systems (FCS) program was the largest and most ambitious planned acquisition program in the Army's history. As a program it was intended to field not just a system, but an entire brigade: a system of systems developed from scratch and integrated by means of an advanced, wireless network. Moreover, the FCS-equipped brigade would operate with novel doctrine that was being developed and tested along with the materiel components of the unit. To paraphrase the Army at the time, FCS *was* Army modernization.

In 2009 the FCS program was cancelled, although some of its efforts continued on as follow-on programs. The FCS program had garnered considerable attention throughout its existence, but few studies have been released documenting the lessons from the program to aid the Army in moving forward from such a large acquisition termination. In 2010, the Army's Acquisition Executive asked RAND Arroyo Center to conduct an after-action analysis of the FCS program in order to leverage its successes and learn from its problems.

This report documents a history and lessons from the FCS program. It should be of interest to the broad acquisition community, as well as those interested in Army modernization, requirements generation, and program management. This research was sponsored by Dr. Malcolm O'Neill, the Assistant Secretary of the Army for Acquisition, Logistics and Technology. It was conducted within RAND Arroyo Center's Force Development and Technology Program. RAND Arroyo Center, part of the RAND Corporation, is a federally funded research and development center sponsored by the United States Army.

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Summary

Background

The Future Combat Systems (FCS) was the largest and most ambitious planned acquisition program in the Army's history. It called for fielding not just one system but an entire suite of systems, all organized into a brigade structure that was envisioned to operate under an entirely new (but not yet fully developed) doctrine while integrated by a wireless network. The scope and reach of the program were remarkable and for a number of years defined *the* modernization effort of the Army.

In 2009 the FCS program was cancelled. Although some of its components have been transferred to other programs, FCS is widely regarded as a failure, which has eroded confidence both inside and outside the Army in the service's acquisition capabilities. The Army has undertaken multiple internal efforts to assess the post-FCS situation, but those efforts have yet to be widely distributed, and moreover the collection lacks an objective, outside voice to ensure an unbiased analysis.

In 2010, the Army's Acquisition Executive (AAE) asked RAND Arroyo Center to conduct an after-action analysis of the FCS program. The purpose of the analysis was twofold. First, Arroyo was to provide a broad, historical look at what happened over the course of the FCS program with the aim of dispelling some myths and providing a backdrop for further discussion within and outside the Army. Second, Arroyo would identify lessons that the Army should carry away from the FCS experience. Some of these the Army has already begun to learn, while others remain to be learned. Arroyo's ultimate goal was to provide lessons that the Army's Acquisition Executive can consider for future development of the acquisition system and for acquiring complex systems of systems (SoS) like the FCS. Our summary judgment of the FCS program is that the Army's intent in creating FCS was largely correct, but the execution faced far too many challenges.

Lessons

We distilled lessons from six aspects of the program: its background; the evolution of cost, schedule, and performance; the requirements process; the program's manage-

ment; the program's contracts; and the program's associated technology. The requirements process was quite lengthy, so we consider it from two perspectives: the generation of the initial requirements and the evolution of requirements during the program.

Lessons from the Background

Wargames are good at identifying issues for resolution, but they cannot be taken as validation of concepts. The original intent of the wargames leading up to the FCS program was to highlight issues. But that intent was lost along the way, and the importance and interpretation of wargame events took on much larger meaning in the Army's concept formulation, solidifying the concepts into Army thinking without the due diligence necessary.

Unspecified assumptions can shape the outcomes of wargames. A key aspect of any analytic effort is to clearly identify assumptions being made and understand how important they are to any conclusions later drawn. The importance of the assumptions underpinning the FCS program is unmistakable and underappreciated when interpreting the outcomes of wargames.

Analytic capabilities are important to the success of large, complex acquisition programs. The development of concepts and the analysis of cost, technical feasibility, risk, and uncertainty all require detailed and sophisticated study. During the FCS program, the Army's capabilities to conduct such analysis were too thinly staffed and not readily heard to affect high-level decisions being made. FCS has shown that technology assessment and analysis capabilities are vital to the effective translation of new force concepts into viable acquisition programs.

Testing technical and other key assumptions underpinning new Army concepts can identify issues crucial to program success. The Army's new concepts for operating during this period of time were monolithic and without alternatives. Concepts such as strategic and operational maneuverability—"see first, decide first, act first"—which led to a tradeoff of armor protection for intelligence and decisionmaking, suggest that the Army did not have a clear grasp of which technologies were feasible and which were necessary and satisfactory to meet the needs of the future. These concepts eventually found their way into the FCS program with little flexibility. Army wargaming and concept development solidified these concepts rather than testing or questioning them, and the technical community was either left out or ineffective in pointing out the problems with the concepts prior to the FCS program start. In the end, those concepts were integrated as early requirements for the FCS program, without technical, operational, or organizational support.

Concept generation and exploration would benefit from increased deliberation, input, and consideration from across the Army. The FCS program showed the importance of understanding the technical underpinnings early on and before wide-scale Army adoption. Additional work early in concept development will be necessary for some time. This entails increasing early interactions among concept developers, the

technical community (both the Army Science and Technology base and industry), and the acquisition community to reach consensus on what is possible from a performance, technical risk, and cost perspective. It also requires changes in how “games” and “experiments” are used in the Army for concept development. Generating alternative concepts from within and outside the Army would also help ensure conceptual robustness.

Lessons from Changes in Costs, Schedule, and Performance over Time

Senior-level involvement can significantly motivate an acquisition effort. Early support for the FCS program was significant from the highest levels within Army leadership and aided in moving a large and complex program into existence quickly. The drive to move FCS forward permeated the program, as pressure mounted to meet early timelines and aggressive requirements. In the end, the senior-level involvement was both good and bad for the program, affecting negatively its ability to flex in light of information about technological and other challenges.

Major program shifts can cause significant turbulence and erode support for an acquisition program. The FCS program faced turbulence manifested through multiple major Army decisions to restructure it as knowledge was gained and as operations in Iraq and Afghanistan evolved. The program restructured two times in significant ways, changed contract types, and added “spin-outs,” all of which added new elements of difficulty into an already ambitious acquisition program. These shifts, and others, made the FCS program difficult to understand and tough to manage, and in many ways this sacrificed internal and external support for the effort.

Cost estimations can be highly uncertain in large, novel programs and subject to various interpretations that can undermine program support. Cost estimation for such a large, complex program was challenging, especially in terms of the software, integration, and life-cycle components. That can lead to disparate estimations, inherent difficulty in determining affordability, and uncertainty among those who develop Army budgets and programs.

Spin-outs are a difficult proposition to be integrated into an acquisition program midstream. The spin-outs in FCS were to capitalize on near-term successes in support of ongoing operations. While the intent was largely useful, the execution was hampered by unclear guidelines and changing intent.

Large, system-of-systems acquisition programs take time. The FCS program, while perhaps remaining a unique acquisition experience for years to come, was progressing slowly compared to the milestones and showed how long such major undertakings can take. The early, aggressive timelines were unrealistic and importantly had to be moved significantly into the future for the program to continue.

Lessons from Requirements Generation

An organization and operation (O&O) plan that takes an integrated unit perspective can aid requirements formulation. From a requirements perspective, perhaps the most useful lesson from the FCS program was that its brigade-level perspective enabled useful approaches to designing concepts, and requirements flowed from this critical starting point. Most significantly, FCS engendered an innovative framework for developing brigade-level requirements, even if some flaws within that framework ultimately prevented it from succeeding in the operational requirements document. Moreover, U.S. Army Training and Doctrine Command (TRADOC) started with a concept of integrated, network-centric operational maneuver, and spelled out in the O&O Plan how component systems and subsystems would interoperate in different types of warfare. The O&O Plan usefully served as a key reference point throughout the program.

A successful program requires a sound technical feasibility analysis. The O&O Plan was compromised by an overreliance on assumptions that the acquisition community could develop and integrate items using both evolutionary and unknown revolutionary technologies. This, in addition to equally optimistic expectations that unprecedented and technically underanalyzed deployability, intelligence, surveillance, and reconnaissance (ISR), and intelligence fusion capabilities would be achieved should have provided early warning of how much the program relied on critical, high-risk assumptions. The two most important capabilities—C-130 transportability and real-time, tactical intelligence—had the weakest technical bases. An approach with a higher likelihood of success might entail earlier, more rigorous analysis of technological forecasts, assumptions, and the operational environment, all of which feed into the O&O Plan. A more cautious approach might simply ensure that revolutionary concepts remain just that, concepts, until underlying technical assumptions have a firmer basis. A specific approach is for the Army requirements community to increase its use of independent evaluators or “red teams” to test requirements while in development, and well before and in the lead-up to Milestone B.

The development of operational requirements requires an integrated, unit-level (not system-level) approach. Despite organizational integration at the combat development level, requirements were not ranked hierarchically early enough, and system-level capabilities were not effectively subordinated to SoS-level ones. Moreover, the large number and specificity of system-level requirements precluded trades to meet SoS-level requirements and constrained the structure of the architecture. Although the operational requirements document (ORD) contained several categories of requirements based on their importance to achieving SoS-level capabilities, ultimately they were all threshold requirements and had the same implicit level of prioritization.

Insufficient analysis and mismanagement of expectations can lead to unrealistically ambitious requirements. These shortfalls resulted partly from the fact that the ORD was developed in a hurry, with too little technical analysis or understanding

of how lower-level requirements would integrate in order to achieve higher-level ones. Since this was the largest integrated set of requirements the Army had ever developed, it was extremely difficult to analyze and understand precisely how all of them would interoperate. Compressing the amount of time allotted to reach such an understanding did not help. Equally problematic, from a requirements perspective, were the ambitious expectations that many officials built up to Congress and the public early in the program. A common grievance was that the “propaganda campaign” rapidly outpaced delivery, making it difficult for program officials to backtrack on promised capabilities and for the user community to relax requirements. The initial, 96-hour strategic deployment objective, for instance, set a high but unrealistic bar without a proper understanding of what exactly it meant for requirements and technologies. In the future, it may be wiser not to set expectations so high, so early, and so publicly, all of which helped make those promises irrevocable. Additionally, when requirements are set and driven at such a high level within the Army, it is that much harder to walk them back if necessary.

Complex system-of-systems acquisitions may require suboptimization of systems to achieve optimized higher-level unit optimization. The Unit of Action Maneuver Battle Lab (UAMBL) did not effectively integrate requirements from a brigade perspective. While UAMBL controlled the ORD, proponent commands controlled many individual requirements that they were allowed to write into the ORD. As UAMBL was composing the ORD, proponent commands introduced many overspecified requirements that, in many cases, UAMBL did not override and rewrite to open trade space critical to optimizing SoS-level performance. Effective generation of unit- and SoS-level requirements therefore demands tighter centralization and more hierarchical organization ranking SoS design and integration responsibilities and authorities clearly above individual systems and Army branches.

Parochial branch interests can hamper achieving overall unit capabilities. Army branches are used to writing requirements to optimize capabilities within their functional areas. But designing an integrated unit from the ground up necessitates prioritizing unit over individual system performance, and optimization of the brigade is rarely compatible with optimization of every individual component.

A detailed description of integrated unit-level operations and functionalities can clarify how individual requirements interact and fit in the operational architecture. Tiering should be only the first step toward developing unit sets of requirements. While system- and subsystem-level requirements were too narrowly defined, brigade-level requirements were too vaguely defined. This created problems for engineers as they began to analyze and decompose the ORD following Milestone B. Often it was difficult to understand exactly how individual requirements interacted with one another and fit into the operational architecture, which was relatively underdeveloped and reportedly marginalized as the program focused on preparing the ORD to pass Milestone B.

A detailed and early operational architecture may connect operational requirements and unit-level concepts more tightly. A bridge is needed between the O&O Plan and the ORD to describe in greater detail how individual requirements are allocated and how they interoperate and interact to achieve higher-level functionalities. Developing a unit-level set of requirements was clearly a step in the right direction, but what is also clear is that greater specificity was needed to describe to engineers what exactly TRADOC wanted the brigade to do, how it would fight, how integrated systems would interact, and how the network would operate. One solution would be to develop an intermediate document between the O&O and the ORD that would describe integrated unit-level function with greater specificity. Although TRADOC fleshed out many of these details, generally this did not occur until after Milestone B.

Designing smaller integrated units could facilitate the development of requirements for large systems of systems. Another practical solution might also be to decrease the size of the unit. Designing requirements for an entire brigade was extraordinarily complex due to its size, the number of systems, and the scale of the network. The idea behind developing a more detailed operational architecture is to describe the complex behavior of the unit more exactly and thus reduce ambiguity about its design.

Lessons from Requirements Evolution

Revalidating operational concepts periodically will ensure that the capability being acquired remains relevant. The Army assumed that the qualities that would enable FCS to dominate major combat operations (MCO), such as tactical agility, maneuverability, precision lethality, and cutting-edge situational awareness, would apply equally to operations other than MCO warfare. The U.S. military's experience in Iraq and Afghanistan disproved this assumption, demonstrating most importantly that no level of currently achievable tactical intelligence could substitute for physical force protection. But this realization was slow to set in, and the FCS operational concept remained static.

Any operational force optimized for one type of warfare will have relative strengths and weaknesses. While the O&O Plan, ORD, and other high-level requirements documents clearly highlighted FCS's strengths, its relative weaknesses were not articulated with equal clarity, even though they were equally important. Such weaknesses should draw at least as much scrutiny and attention as a program's presumed strengths. If changes in the operational environment make those weaknesses increasingly important, or undermine core concepts and assumptions, programs should be flexible enough to adjust concepts and requirements appropriately.

Immature technologies and insufficient understanding of requirements can lead to instability and significant changes later. The FCS program after Milestone B illustrates the importance of thorough technical understanding of requirements before transitioning to the system development and demonstration (SDD) phase. Because requirements developers lacked solid technical understanding and analysis of many

requirements, largely because many of the technologies were underdeveloped and immature, they let those requirements remain flexible by not inserting threshold values in the first version of the ORD. But the lack of firm requirements created problems for engineers as they began developing design solutions for requirements that remained unsettled and continued to change in major ways more than two years after Milestone B.

Over the course of the FCS program, the structure and content of the requirements moved closer to a true “integrated” set. Many requirements and individual systems were aligned, scaled back, or eliminated, and engineers and combat developers increasingly worked together to understand how interconnected systems would work together, in addition to how their requirements should be written to foster interaction between component systems and to enable SoS-level capabilities. But the history of the FCS program after Milestone B suggests that significantly more work is needed to fully appreciate the difficulty of and best approaches to such a broad, complex undertaking.

Lessons from Program Management

Large-scale integration and development projects require significant in-service integration and engineering capabilities. The use of a Lead Systems Integrator (LSI) in the early 2000s was supported by many government officials and outside organizations and was rational in its broad intent, though later restricted in its execution. The Army’s need for significant engineering and integration capabilities to meet ambitious goals was clear, and industry—at the time—was largely seen as the best choice. As the Army moves toward the future and continues its development of brigade capabilities, FCS has shown how difficult from a management standpoint that will be.

Building brigade-level capabilities can enhance the ability to integrate systems into larger formations. The general acquisition strategy to consider Army capabilities in terms of larger formations and at the SoS level of detail was largely seen as supportable throughout our discussion with program officials and outside experts. Program officials we interviewed largely agreed that the trend toward networked capabilities will increasingly demand movement away from acquisition of platforms in isolation and toward a more sophisticated consideration of how the Army should integrate systems into existing and future formations. FCS was a large step in that direction for the Army, albeit one that failed due to an unrealistic understanding of enabling technology maturity and an overly ambitious schedule for a very complex program.

Up-front system engineering and architecting are critical. Only certain aspects of systems integration can be concurrent, and most steps are necessarily sequential. Every veteran of the FCS program agreed that more preparatory system engineering is needed for such a large, ambitious program. SoS engineering should have been much stronger early in the program, entailing calling upon a deeper collection of system engineering and architecting (SE&A) experts within the Army. The Army has an opportunity to do so in the future, pulling from the work accomplished in FCS, and

building toward a coherent future. Current Army management should consider consistently enforcing DoD's revamped acquisition policies to include the requirement for early system engineering and completion of a first preliminary design review before Milestone B.

Concurrent development of the system-of-systems can complicate acquisition. In hindsight, it is clear that pursuing a revolutionary acquisition that was vast in scope and reliant on key elements being conducted concurrently with immature technology was far too complex an undertaking for the Army and the LSI to manage. Compared to more traditional acquisition strategies, the SoS approach significantly increased both the complexity of the organizations needed to execute the FCS program and the technical challenges associated with system engineering, software engineering, and system integration. The program's initial, overly ambitious schedule (see Figure 6.1) was ultimately jettisoned in part due to early budget decrements, which hampered the planned synchronization of SoS component launches and schedule adherence. Remedies for the inherent difficulties in this unprecedented concurrency and aggressive schedule are likely not even available. Past, common recommendations to simply not start engineering and manufacturing development (EMD) without mature technologies hold true for the FCS experience.

Quality personnel in the services are essential to acquiring complex systems of systems. The LSI succeeded in bringing industry leaders and their top talent to the FCS program, and the Army generally managed to recruit the best talent from its service and from the wider DoD acquisition community as well. Even so, the personnel "bench" was not deep, particularly on the government side, for such an ambitious undertaking. Key areas were developed in real time, including the significant capabilities built on the Army side to perform network analysis and SoS engineering. The government was particularly short on technical experts, and repeated changes to the FCS program diverted some of their efforts. The government's general shortage of acquisition talent remains to this day.

A strong acquisition capability will enable the services to assess industry performance in complex programs. The Army intended to undertake a "new paradigm" in its FCS acquisition strategy—an unprecedented partnership between industry and government was deemed necessary to bring the best talent to the program and to execute its aggressive schedule. However, this objective was never fully accomplished. The new paradigm was hampered by distrust, evolving roles and responsibilities, and general uncertainty on what to expect from each partner. These problems caused communication issues within the structures, and opened potential gaps in the Army's ability to monitor and effectively manage progress. In response, the Assistant Secretary of the Army for Acquisition, Logistics and Technology (ASA(ALT)) should ensure that any future attempt to establish a partnership-type arrangement with industry requires the Army to maintain a strong internal capability to assess the performance of the commercial firms it engages for the purpose.

Integration organizations allow the enforcement of SoS discipline and can curb parochial branch influences. Many organizational lessons can be pulled from the FCS experience based on the successes and problems encountered. The scope of the FCS program, in terms of the systems and network it represented, mirrored many of the organizations existing in the Army—aviation, ground combat systems, artillery, and the like. In addition, the FCS program had integrating elements to help facilitate tradeoffs. The entrenched communities in the larger Army were also evident in the FCS program, as challenges arose in enforcing SoS-level thinking on the community and communicating difficult problems through the chains of command. The philosophy behind the FCS program—that SoS level integration would develop through complex interactions at multiple command levels—was a good start to a very difficult and complex problem.

Top-level organizations can ensure senior leaders involvement in important decisions. Various top-level organizations—both standing like the One Team Council (OTC) and FCS Board of Directors, and ad hoc like the FCS Team One—provided needed senior leader involvement in important decisions. Despite early concerns about the efficiency of those organizations, many thought they served useful roles during FCS and encouraged ownership and buy-in from across the Army. These types of organizations provide some lessons for future integration within the Army. Specific to the near future, we recommend that ASA(ALT) evaluate the potential use of FCS OTC- and BoD-like structures in future complex acquisition programs. Additionally, ASA(ALT) may wish to examine the FCS Team One experience for SoS integration lessons learned and evaluate its organizational construct to consider the use of Team One-type bodies in future complex acquisition programs.

Oversight and independent review by technically qualified personnel can provide crucial assessments of performance and risk. The Army's program management strategy included enhanced oversight mechanisms for Office of the Secretary of Defense (OSD) authorities. However, despite the OSD oversight opportunities touted at the beginning of FCS, the Government Accountability Office (GAO) found that OSD failed to exercise adequate oversight until late in the program. The FCS program also employed various independent review teams in an attempt to get objective assessments of its performance and risks. Yet program officials thought that, in the end, the review teams too often lacked the expertise needed to make sound judgments, lacked objectivity due to conflicts of interest (i.e., many team members had worked on or otherwise maintained a relationship with the FCS program), and/or lacked the necessary stature needed to influence the program. The 2009 Weapon Systems Acquisition Reform Act may result in enhanced capabilities for OSD oversight of Army and other service acquisition programs. However, an expansion of roles should also be explored to include Independent Review Teams (IRTs) in program management reviews and nonadvocacy reviews. The ASA(ALT) should consider evaluating approaches to the

establishment of truly independent review teams that can provide objective assessments of weapon acquisition cost, schedule, technical performance, and risk.

Service visibility into and influence over subcontracting activities can foster competition and ensure commonality across platforms. The LSI proved adept at rapidly competing and executing subcontracts for major SoS components, and the program achieved a diverse supply base. Moreover, the government's co-leadership of Integrated Product Teams (IPTs) enabled it to play a role in the selection of subcontractors for the FCS program and the Army could veto LSI source selections. The GAO has stated that the government's visibility into lower tiers of the LSI structure also enabled it to promote competition among lower-level suppliers and "ensure commonality of key subsystems across FCS platforms."

Consideration of and coordination with complementary programs can identify problems and enable mitigation strategies. FCS was ambitious in its attempt to build brigade-level capabilities and thus necessarily would affect and be affected by programs from across the Army and other services. The articulation of complementary programs—numbering over a hundred at times during the program—was not well founded on fundamental systems theory, but was widely seen as a necessary step in building to brigade-level requirements. Program senior leaders understood the risks of relying on complementary programs, yet a formal complementary programs management plan had not been completed at SDD kickoff. According to a senior program official, complementary programs were also not considered in the initial LSI contract, and fewer than half of the required interfaces had been explored by 2009. Program veterans we interviewed universally stated that funding needed to develop and implement Interface Control Documents (ICDs) was either insufficient or nonexistent. Regarding the essential JTRS and WIN-T programs, interface summits were initiated, but these efforts came far too late to salvage the interfacing process. Indeed, for a period of several years, engineers on these two programs were restricted from even communicating with their colleagues on the FCS program, as JTRS and WIN-T managers were concerned about reports of technical challenges being shared with personnel outside of their programs.

Lessons from Contracts

Government control over significant elements of the system of systems may make incentive fees inappropriate. The FCS program structure made it difficult to award the LSI less than all available performance fees. The government retained such significant control over so many of the factors that would affect FCS SoS behavior, and because it was embedded into the IPT structure with some level of authority, the LSI could always point to government actions as a proximate cause of performance issues.

Performance incentives not tied to actual product performance may not result in effective outcomes. The ambitious performance goals and aggressive schedule for the FCS program destined it to unstable requirements. Performance incentive fees

based on actual product performance cannot be realistically drafted when product requirements cannot be fixed.

Programs with a combination of unstable requirements and complex integration are candidates for fixed or award fee contracts rather than incentive contracts. Significant performance, cost, and schedule uncertainty needs to be mediated through contract design. Large development programs may be inappropriate for contracts that reward only expected performance. The Federal Acquisition Regulation (FAR) advises that schedule and cost incentives should reward improved, rather than expected, performance. Large development contracts generally take years to complete and are difficult throughout all phases.

Early commitment of incentive fee reduces the available fee late in the program when it might be more necessary. Early commitment can also significantly reduce the government's ability to motivate contractor behavior as the program enters final design and test and moves to production.

Lessons from Technology

Significant technology development should not occur late in acquisition programs. The Army will always need to push the bounds of technology to keep ahead of the threat and meet the needs of the nation. However, that technical development must be rooted in exploratory basic science and advanced development programs validated by early and realistic field experimentation with real products, and not in SDD phases of major acquisition programs.

Documentation of the state of the art for each critical technology element will identify risk and areas for increased investment. Future programs should analyze and document the state of the art for each critical technical element (CTE), using metrics found in scientific literature. Not only is this a common practice in technology development, it would also readily justify the need to invest in developing each critical technology rather than using existing implementations. Furthermore, a quantifiable metric relevant to each CTE will clearly convey the ambitiousness of what is achievable at present and what is required for SoS functionality.

Alternative technology assessment metrics can supplement technology readiness levels (TRLs), which may be inadequate for some aspect of SoS acquisitions. Although TRLs are a valuable metric for determining the maturity of individual CTEs, they may not appropriately address system integration or the system as a whole. There are other metrics relevant to key characteristics of FCS systems that need further development. An example is integration readiness levels (IRLs), which have been shown to highlight low levels of integration maturity, whereas a specific mathematical combination of TRL and IRL has been advocated to produce a system-wide metric of readiness called the SRL. TRLs, MRLs, and SRLs are critical to objective measuring of the maturity of a technology. These metrics, as well as CTEs, help determine the

extent to which the technology is appropriate for the solution and guide the development of downstream user evaluation criteria.

Including leading technical practitioners on internal review teams (IRTs) can help determine technology maturity and improve accuracy of IRT assessments. The wide range of scientific and engineering disciplines required to assess the maturity of all 44 CTEs meant that the IRT relied on subject matter experts (SMEs) to form its conclusions. The IRT is a primary tool for the ASA(ALT) to provide an accurate and objective determination of technology maturity. It will be important to consider expanding the membership to technical practitioners drawn from engineering disciplines underlying the CTE, who have hands-on experience in industry or in advanced research centers.

Using SoS requirements to identify complementary programs (CPs) can help schedule synchronization issues. Formally recognizing program interdependencies is an acquisitions requirement, but an overly expansive list of CPs can generate a perception of greater complexity than can be afforded by the program's timeline or resources. This identification of CPs should be based on technical requirements and the SoS specifications. Each CP should be linked to either producing a CTE or providing a system function—noting that many CPs are legacy capabilities that will need to interoperate with the new system. Analysis of how the SoS concept will rely on the specific technology solutions provided by the CPs requires input from the requirements, analysis, and systems engineering communities and should be done before the Milestone B review.

The history of synchronization across multiple programs is thin, with notable examples of preplanned product improvement efforts, which typically are limited in scope as well as duration. At cancellation, the FCS program had not reached the point of defining exactly how new increments of technology would be spiraled into FCS-equipped brigades.

Having too many connections to or being too highly dependent on outside programs can lead to significant risk. The FCS program was expected to interoperate with many legacy or developmental radio systems, with JTRS and WIN-T being the most well known. However, FCS struggled for the first two to three years to understand the status of JTRS. Furthermore, the ORD specified JTRS as the primary radio for FCS, discouraging analysis of alternative radios that, although less capable, may have provided some fraction of desired operational capabilities. As a result, FCS depended entirely on the JTRS radios, a CTE, to create the network that would enable the SoS to provide the requisite situational awareness for lethality and survivability. Future acquisition programs must ensure that any CTE provided by a CP has backup plans or actual internally funded alternatives to reduce risks from design changes or schedule synchronization.

Risk mitigation strategies that incorporate SoS engineering practices will facilitate risk mitigation across systems. Despite the lack of best practices for risk mitigation in SoS acquisition, it was asserted that the FCS risk management process was more rigorous than the standard DoD approach, using best practices available and

being executed at the lowest levels. Nonetheless, risk mitigation should incorporate SoS engineering practices, particularly exploring risk trades between systems. Such trades are especially important when systems require novel technologies with unavailable implementations so that the full parameter space of technical mitigation options may be explored.

A shared modeling and simulation repository can improve the fidelity of mission-level analysis. Our interviews have indicated a lack of such awareness and the need to consolidate the disparate modeling and simulation (M&S) activities beyond just organizational structuring. One concrete suggestion is to build a model data and documentation repository as part of the Army Acquisition M&S Enterprise Solution (AAMSES, previously known as 3CE) to allow different analysts to translate improvements in one level of the modeling hierarchy to the next and thereby improve the fidelity and utility of mission-level analysis. These improvements in mission-level analysis would allow a broader understanding of the type of CONOPS capabilities provided by the SoS and also support design decisions for individual systems.

Incorporating mission-based vignettes in developmental test adds robustness to vignettes planned for operational tests. Even in early system development, the parameters of any mission-based vignette may influence testing conditions, which otherwise may be determined in an ad hoc fashion. To realize this paradigm of capabilities-based testing will require earlier coordination between network developers, mission-level analysts, relevant system developers, and the test community to ensure a consistent translation of vignette parameters to physical test conditions, with accurate network assumptions.

Influencing S&T priorities by the AAE will help ensure their relevance to current threats and future missions. The AAE should place greater emphasis on requiring further-term capabilities to demonstrate their relevance to current threats in addition to future projected missions. Current policy requires a technology transfer agreement (TTA) at least 12 months before completion, and that should be extended to develop a “preliminary TTA” at the inception of an Army technology objective to allow greater interaction between the science and technology (S&T) community and program managers in the acquisition community. Such an earlier agreement may allow S&T efforts more visibility of changing acquisition emphasis between near- and further-term needs, while providing the acquisition community greater flexibility in tailoring incremental deliverables to ensure some output prior to any shifts in S&T resource allocation that may be required by ongoing operational demands. Generally, FCS program officials considered S&T easier to interface with than complementary programs, due to the flexibility provided by the technology objective mandates to transition into a program of record.

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Acronyms

3CE	Cross-Command Collaboration Effort
AAE	Army Acquisition Executive
AAMSES	Army Acquisition M&S Enterprise Solution
AAN	Army After Next
ACE	Advanced Collaborative Environment
ACP	Army Cost Position
ADM	Acquisition Decision Memorandum
AETF	Army Evaluation Task Force
AFV	Armored Family of Vehicles
AIG	Analysis Integration Group
AMC	Army Materiel Command
AMRDEC	Aviation and Missile Research, Development, and Engineering Center
AMSAA	Army Materiel Systems Analysis Activity
AoA	Analysis of Alternatives
APB	Acquisition Program Baseline
APS	Active Protection Systems
APUC	Average Procurement Unit Cost
ARCIC	Army's Capabilities Integration Center
ARL	Army Research Lab
ARM	Active Risk Manager
ARV	Armed Robotic Vehicle
ASA(ALT)	Assistant Secretary of the Army for Acquisition, Logistics and Technology
ASARC	Army System Acquisition Review Council

ASM	Armored Systems Modernization
ASR	Acquisition Strategy Report
ASTAMIDS	Airborne Standoff Minefield Detection System
ATO	Army Technology Objective
AUPC	Average Unit Procurement Cost
AUSA	Association of the United States Army
BAA	Broad Agency Announcement
BCT	Brigade Combat Team
BCTM	Brigade Combat Team Modernization
BDA	Battle Damage Assessment
BES	Budget Estimate Submission
BLOS	Beyond Line of Sight
BoD	Board of Directors
BoK	Book of Knowledge
C2	Command and Control
C2V	Command and Control Vehicle
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CABs	Combat Aviation Brigades
CAIG	Cost Analysis Improvement Group
CASCOM	Combined Arms Support Command
CBA	Capability-Based Assessment
CBO	Congressional Budget Office
CBRN	Chemical, Biological, Radiological, Nuclear
CBRS	Concept Based Requirements System
CDD	Capability Development Document
CDR	Critical Design Review
CERDEC	Communications-Electronics Research, Development and Engineering Center
CES	Communications Effects Server
CHPS	Combat Hybrid Power Systems
CJCS	Chairman of the Joint Chiefs of Staff
CL/U	Container Launch Unit

CMMI	Capability Maturity Model Integration
CMO	Contract Management Office
COICs	Critical Operational Issues and Criteria
CONOPS	Concepts of Operation
COP	Common Operational Picture
COTS	Commercial Off the Shelf
CP	Complementary Program
CPI	Cost Performance Index
CPIF	Cost, Plus Incentive Fee
CSA	Chief of Staff of the Army
CTD	Concept and Technology Demonstration
CTE	Critical Technology Element
DAB	Defense Acquisition Board
DAE	Defense Acquisition Executive
DAES	Defense Acquisition Executive Summary
DARPA	Defense Advanced Research Projects Agency
DASA(CE)	Deputy Assistant Secretary of the Army for Cost and Economics
DASA(R&T)	Deputy Assistant Secretary of the Army for Research and Technology
DAU	Defense Acquisition University
DCMA	Defense Contracting Management Agency
DDR&E	Director of Defense Research and Engineering
DFARS	Defense Federal Acquisition Regulations Supplement
DIA	Defense Intelligence Agency
DIACAP	DoD Information Assurance Certification and Accreditation Process
DoD	Department of Defense
DOORS	Dynamic Object-Oriented Requirements System
DOTMLP-F	Doctrine, Organization, Training, Materiel, Logistics, Doctrine, Personnel and Facilities
DPM	Deputy Program Manager
E3I	Electromagnetic Environmental Effects Interference
EAC	Estimate at Completion

EBCT	Evaluation Brigade Combat Team
ECC	Essential Combat Configuration
ECP	Engineering Change Proposal
EFP	Explosively Formed Penetrator
EGG	Eject Gas Generator
E-IBCT	Early Initial Brigade Combat Team
EMD	Engineering and Manufacturing Development
EMRL	Engineering and Manufacturing Readiness Level
EVMS	Earned Value Management System
FAA	Functional Area Analysis
FAR	Federal Acquisition Regulation
FBCT	FCS Brigade Combat Team
FCC	Full-Combat Capability
FCS	Future Combat Systems
FCV	Future Combat Vehicle
FFID	Future Force Integration Directorate
FMRV	FCS Maintenance and Recovery Vehicle
FOC	Full Operational Capability
FRP	Full-Rate Production
GAO	Government Accountability Office
GCS	Ground Combat Systems
GCV	Ground Combat Vehicle
GIG	Global Information Grid
GMR	Ground Mobile Radios
GOTS	Government off the Shelf
GSTAMIDS	Ground Standoff Mine Detection System
GWOT	Global War on Terror
HAS	Hit Avoidance Suite
HBCT	Heavy Brigade Combat Team
HEMP	High-Altitude Electromagnetic Pulse
HFE	Heavy Fuel Engine
HMMWV	High Mobility Multipurpose Wheeled Vehicle

HMS	Handheld, Manpack and Small Form Fit
HNW	Highband Networking Waveform
I&V	Integration and Verification
I2WD	Intelligence and Information Warfare Directorate
IAAPS	Integrated Army Active Protection System
IATO	Interim Authorization to Operate
IAV	Interim Armored Vehicle
IBCT	Infantry Brigade Combat Team
IBCT	Initial Brigade Combat Team
ICD	Interface Control Document
ICE	Independent Cost Estimates
ICV	Infantry Combat Vehicle
IDA	Institute for Defense Analyses
IDE	Integrated Data Environment
IDM	Information Dissemination Management
IED	Improvised Explosive Device
IEW&S	Intelligence, Electronic Warfare, and Sensors
IMP	Integrated Master Plan
IMS	Intelligent Munitions System
IMS	Integrated Master Schedule
IOC	Initial Operational Capability
IOT&E	Initial Operational Test and Evaluation
IPR	In-Process Review
IPT	Integrated Product Team
IR	Infrared
IRAD	Independent Research and Development
IRT	Independent Review Team
ISR	Intelligence, Surveillance, and Reconnaissance
JCIDS	Joint Capabilities Integration Development System
JROC	Joint Requirements and Oversight Committee
JTRS	Joint Tactical Radio System
kph	Kilometers per hour

KPP	Key Performance Parameter
LAV	Light Armored Vehicle
LCA	Life-Cycle Architecture
LCC	Life-Cycle Cost
LCCCP	Life-Cycle Cost Containment Plan
LCCE	Life-Cycle Cost Estimate
LOS	Line of Sight
LRC	Long-Range Countermeasures
LRIP	Low-Rate Initiation Production
LSI	Lead Systems Integrator
LUT	Limited User Tests
M&S	Modeling and Simulation
MAA	Mission Area Analysis
MANET	Mobile Ad Hoc Network
MAV	Micro Air Vehicle
MBCTs	Modular Brigade Combat Teams
MCO	Major Combat Operations
MCS	Mounted Combat System
MDAP	Major Defense Acquisition Program
MGV	Manned Ground Vehicles
MILCON	Military Construction
MILDEP	Military Deputy to the ASA(ALT)
MNA	Mission Needs Analysis
MNS	Mission Needs Statement
MOA	Memorandum of Agreement
MPRI	Military Professional Resources Inc.
MRAP	Mine Resistant Ambush Protected
MRC	Major Regional Conflict
MTMCTEA	Military Traffic Management Command Transportation Engineering Agency
MULE	Multifunctional Utility/Logistics and Equipment
NAUS	Near-Autonomous Unmanned System

NDA	National Defense Authorization Act
NIK	Network Integration Kit
NLOS-C	Non Line of Sight Cannon
NLOS-LS	Non Line of Sight Launch System
NLOS-M	Non Line of Sight Mortar
NM	Nautical Mile
NMS	Network Management System
NSA	National Security Agency
O&O	Organizational and Operational
O&S	Operations and Support
OE/CE	Operational Evaluation/Certification Exercise
OFTF	Objective Force Task Force
OIPT	Overarching Integrated Product Teams
OMB	Office of Management and Budget
ONA	Office of Net Assessment
OneSAF	One Semi-Automated Forces
ORD	Operational Requirements Document
OSD	Office of the Secretary of Defense
OSD(PAE)	Office of the Secretary of Defense (Program Analysis and Evaluation)
OT	Other Transactions
OTA	Other Transaction Agreement
P&E SIL	Power and Energy Systems Integration Laboratory
PAE	Program Analysis and Evaluation
PDOTA	Program Definitization Other Transaction Agreement
PDR	Preliminary Design Review
PEO	Program Executive Officer
PEO-I	Program Executive Officer–Integration
PIA	Procurement Integrity Act
PIDS	Prime Item Development Specifications
PIM	Paladin Improvement Program
PIO	Program Integration Office

PM	Program Manager
PM-CCS	Project Manager for Close Combat Systems
PMBP	Program Management Best Practice
PMO	Project Managing Office
POE	Program Office Estimate
POM	Program Objective Memorandum
QoS	Quality of Service
RA	Research Announcement
RDEC	Research, Development and Engineering Centers
RDECOM	Research, Development and Engineering Command
RDT&E	Research, Development, Testing and Experimentation
RFPs	Requests for Proposals
RGS	Requirements Generation System
RMA	Revolution in Military Affairs
RMP	Risk Management Plan
ROI	Return on Investment
RRC	Requirements Review Council
RSTA	Reconnaissance, Surveillance, Targeting, and Acquisition
RSV	Reconnaissance & Surveillance Vehicle
S&T	Science and Technology
SA	Situational Awareness
SA/SU	Situational Awareness and Understanding
SaaS	Soldier as a System
SAR	Selected Acquisition Report
SBA	Simulation Based Acquisition
SBCT	Stryker Brigade Combat Team
SDD	Systems Development and Demonstration
SE&A	System Engineering and Architechting
SEMP	System Engineering and Management Plan
SEP	Systems Engineering Plan
SIL	Systems Integration Laboratory

SMART	Simulation and Modeling for Acquisition, Requirements and Training
SME	Subject Matter Experts
SMOA	Subordinate Memorandum of Agreement
SoRC	Statement of Requirement Capabilities
SoS	System of Systems
SoSCOE	System of Systems Common Operating Environment
SoSS	System of System Specifications
SPI	Schedule Performance Index
SpI	Special Interest
SRC	Short Range Countermeasures
SSP	Simulation Support Plan
STAR	System Threat Assessment Report
STEP	Simulation Test and Evaluation Process
STO	Science and Technology Objective
SUGV	Small Unmanned Ground Vehicle
SWaP	Space, Weight, and Power
TACOM	Tank-automotive Command
TARDEC	Tank Automotive Research, Development and Engineering Center
TCM	TRADOC Capabilities Managers
TEMP	Test and Evaluation Master Plan
TINA	Truth in Negotiations Act
TIRT	Truly Independent Review Teams
TMA	Technology Maturity Assessment
TOA	Total Obligation Authority
TPM	Technical Performance Measures
TOE	Table of Organization and Equipment
TRA	Technology Readiness Assessments
TRAC	Training and Doctrine Command Analysis Center
TRAC-WSMR	TRADOC Analysis Center at White Sands Missile Range
TRADOC	Training and Doctrine Command
TRL	Technology Readiness Level

TSM	TRADOC Systems Manager
TTA	Technology Transition Agreements
TTP	Tactics, Techniques and Procedures
UA	Unit of Action
UAMBL	Unit of Action Maneuver Battle Lab
UAV	Unmanned Aerial Vehicle
UGS	Unmanned Ground Sensors
UGV	Unmanned Ground Vehicles
USAF	United States Air Force
U.S.C.	United States Code
USD(AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics
USMC	U.S. Marine Corps
USN	U.S. Navy
VCSA	Vice Chief of Staff of the Army
VTOL	Vertical Takeoff and Landing
WIN-T	Warfighter Information Network–Tactical
WIPT	Working-level Integrated Product Team
WSMR	White Sands Missile Range

Introduction

Background and Purpose

The Army's Future Combat Systems (FCS) acquisition program was envisioned to revolutionize the way the Army fights and replace existing combat units with interconnected, integrated assets linked by a central communications network. At about \$200B, FCS was the largest acquisition program ever attempted by the Army, and it represented a significant leap forward in terms of technology, program concept, industry interaction, and acquisition approach. FCS would field entire brigades outfitted with new, lighter, more mobile technologies protected by improved sensors and superior situational awareness.

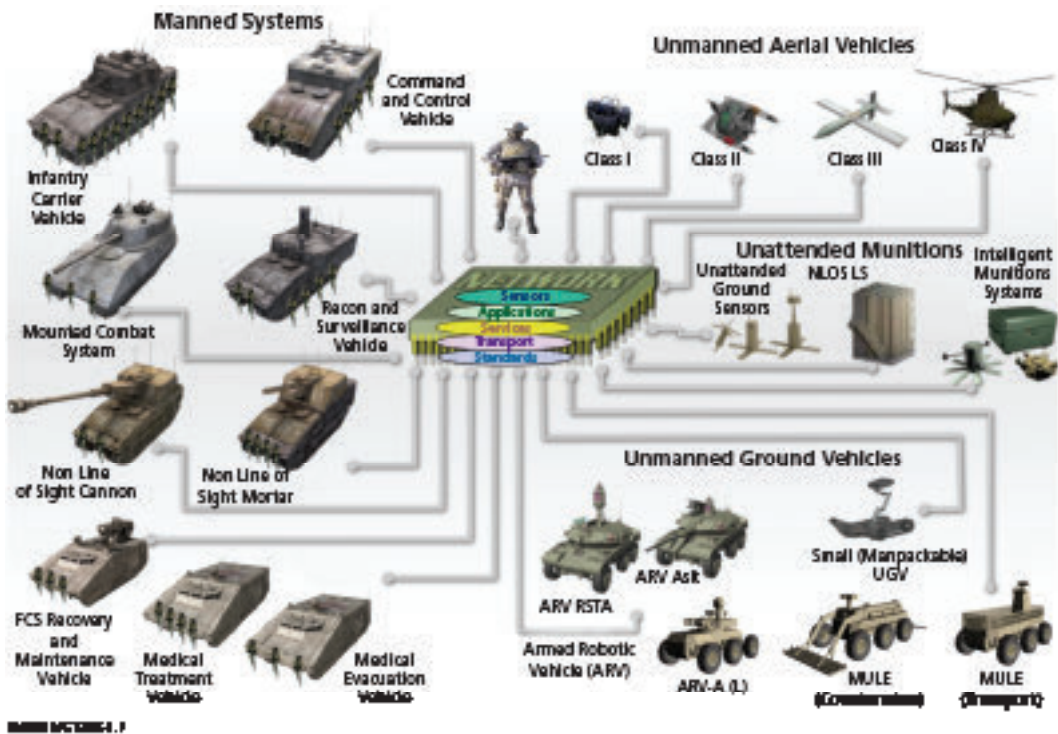
In a speech at the annual Association of the United States Army (AUSA) symposium on October 12, 1999, General Eric Shinseki outlined his vision for a transformational set of technologies that would make the Army "light enough to deploy, lethal enough to fight and win, survivable enough to return safely home . . . and lean and efficient enough to sustain themselves whatever the mission."¹ The new force structure would consist of lighter, more mobile manned, unmanned, and robotic vehicles designed to track and outmaneuver enemies through effective information sharing.²

As the program was conceived, it would consist of 18 systems plus a network (Figure 1.1). It would be described as the "18 plus 1" systems that comprised FCS. Later, the program would add to that vision by inclusion of the soldier in the list of systems, hence ending with "18 plus 1 plus 1" FCS systems, or written "18+1+1." The systems included a number of manned ground vehicles, unmanned air and ground systems, and unattended munitions and sensors all interconnected in a ubiquitous, wireless network.

¹ Army Test and Evaluation Command, Aberdeen Proving Ground, 2006. Scott Flood and Paul Richard, "An Assessment of the Lead Systems Integrator Concept as Applied to the Future Combat System," *Defense Acquisition Review Journal*, December 2005–March 2006.

² Andrew Feickert, *The Army's Future Combat System (FCS): Background and Issues for Congress*, Congressional Research Service Report for Congress, Order Code RL32888, 2006.

Figure 1.1
The 18+1+1 FCS Systems



The program achieved Milestone B in 2003, becoming an official acquisition program among concerns about technological immaturity, schedule slips, and cost escalation. Over the next several years, vague and over-ambitious requirements, lack of mature technologies, and unforeseen risks prevented steady development progress. The Future Combat Systems acquisition program was cancelled on June 23, 2009.

Although some of its components have been transferred to other programs, FCS is widely regarded as a failure, which has eroded confidence in Army acquisition capabilities from those both inside and outside the Army. The Army has undertaken multiple internal efforts to assess the post-FCS situation; however, those efforts have yet to be widely distributed and the collection lacks an objective, outside voice to ensure an unbiased analysis. Accordingly, the Army's Acquisition Executive (AAE) asked RAND Arroyo Center in the summer of 2010 to undertake a lessons-learned study on FCS. The analysis had two purposes: First, provide a broad, historical look at what happened over the course of the FCS program with the aim of dispelling some myths and providing a backdrop for further discussion within and outside the Army. Second, identify lessons that the Army should carry away from the FCS experience. Some of the lessons from FCS the Army has already begun to learn, and others remain to be learned.

While the report analyzes the FCS program, the purpose is not simply to do a post-mortem. The goal is to provide recommendations that the AAE can consider for future development of the acquisition system, especially as it pertains to acquiring complex system-of-systems capabilities.

Sources for This Report

The large size and expansive scope of the FCS program means that only the broad lessons can be captured in any study such as this. This study builds on both qualitative and quantitative sources. Prior research by RAND on the technologies envisioned in FCS, reports about the early transition from the Defense Advanced Research Projects Agency (DARPA) to the Army, contracting incentives, and other sources were included. This study was also informed by multiple draft after-action reports generated by the Army and other organizations. Many of these had important findings from which we could build. They include:

- The Army's 2009 "After Actions Report on FCS."
- Objective Force Task Force After Action Report
- Specific analysis provided to us by the PEO (Integration) on return on investment from the FCS program.
- A draft FCS after-action report written by the Center for Military History; individual interview transcripts.
- A wide variety of official documentation from the program, including plans, strategies, and an incredible number of internal and external briefings over the past ten years of FCS.
- A history of FCS supporting analysis.

The report is also based on numerous interviews, focused on business leaders in the program from both the Army and the Lead Systems Integrator, and Integrated Product Team leads for portions of the program with particular attention to the system-of-system attributes and the network. The interviews were not for attribution, and thus some names are not included in the list of contributors in Appendix A.

Organization of This Report

This report includes many lessons for the Army to consider as it moves toward the future. For the most part, however, the lessons from FCS program are similar to those identified in other acquisition studies. This study organizes the story and lessons of the FCS program into nine chapters.

Chapter Two is a short history of the years leading up to the FCS acquisition program. Here we illustrate how concepts and visions of the future impact the genesis of large-scale programs.

Chapter Three charts the cost, schedule, and composition changes of the FCS program over time. It shows how the Army restructured the program in major ways throughout and provides a baseline for considering subsequent chapters.

Chapters Four and Five provide a detailed description of how the requirements for FCS were generated and how they developed over time. It ends with recommendations on how best to structure, organize for, and refine unit-level requirements in future large-scale programs.

Chapter Six describes the key program management aspects of the FCS program, how it was organized, and how it executed its functions.

Chapter Seven has a breakdown of the contracts used in the FCS program, including the transition of Other Transaction Agreement (OTA) to Federal Acquisition Regulation (FAR), and the challenges with incentivizing a contractor in such a large acquisition program.

Chapter Eight tracks technologies from the original choice through their development. It follows the critical technologies over time and describes a few of the more revolutionary expectations included in the FCS program.

Chapter Nine provides a short summary of the main themes in the document.

Background of the Future Combat Systems Program

This chapter examines how the FCS program got its start, with emphasis on key strategic, operational, and technological concepts and assumptions that were the basis of the program. It begins by analyzing the imperatives and strategic context that drove the Army to consider a sweeping change in its doctrine and force structure.

Recognizing the truth behind the adage, “hindsight is always 20/20,” we conclude with a short list of lessons that the Army may consider when moving forward with future concepts. It then turns to the assumptions that underpinned the FCS program. Always critical to any major acquisition program, these were especially important to the FCS program because it was departing so radically from past experience. Essentially, it was sailing into uncharted waters, which made it particularly vulnerable should the assumptions prove invalid.

Strategic Contexts of the 1990s Informed Capabilities

In 1989 the Cold War ended. That event shifted significantly and almost instantaneously the underpinnings of substantial investments in Army concepts of operation and strategic vision. Over the next few years, the Army would begin to become CONUS-based, with conflicts such as North Korea and European nations becoming less acceptable. Two big operations during that decade would play pivotal roles in how key tenets of FCS came about. The first, in 1991, was the Army’s inability to deploy quickly with anything but a lightly armored brigade to halt Iraqi forces entering Kuwait, which created consternation in many Army thinkers as they watched the Army build up its forces for six months prior to any actual engagements. At that time, the perceived strategic risk of that delay caused many to envision a much more deployable Army as a necessary requirement for the future. Later in the 1990s, Task Force Hawk (NATO operations in Kosovo) provided a bookend in operations, pushing the Army to consider its ability to affect at long ranges and in short order. With a two-month buildup, the Army found its relevance threatened.

During the 1990s there was also a growing acceptance of key tenets of what was becoming known as “military transformation.” The guiding documentation of the ser-

vices had accepted a changing “character”¹ of the military predicated on the integration of advanced technologies and new concepts and organizations to usher in the new era. Similarly, the future, as laid out in Joint Vision 2010,² provided a joint vision for information superiority, which would be a hallmark of the future military. The strategic context at that time was often described as a short list of specific capabilities that included precision, long-range guided weapons; enhanced communication capabilities in both breadth and depth to allow the sharing of information; and advanced fusion of information enabling superior decision making.³ These concepts came up commonly, with well-known individual examples, and few disputing their importance.

Since the early days of the Army, units have been redesigned to meet changing operational needs and to adapt to new warfighting concepts.⁴ Following a long history of updates, during the early and mid-1990s the Army was on a path to transform its force through the application of digital technologies in what was known as Force XXI.⁵ The Army’s view was consistent with the ongoing revolution in military affairs,⁶ and it hinged on exploiting changes in military information technologies to change the way the Army would fight. The Army developed the Force XXI concept through deliberate experimentation and unit design reviews, and installed a technological focus in the conceptual model offered by U.S. Army Training and Doctrine Command (TRADOC).⁷ The TRADOC model was evolutionary in title but recognized the at-times revolutionary effects technological developments might have on an Army when seen in retrospect:

Information Age technology, and the management ideas it fosters, will greatly influence military operations in two areas: one evolutionary, the other revolutionary; one we understand, one with which we are just beginning to experiment. Together,

¹ Office of the Secretary of Defense, *Report of the Quadrennial Defense Review*, May 1997, p. 7.

² Chairman of the Joint Chiefs of Staff, “Joint Vision 2010,” Washington, D.C.: Pentagon, 1997.

³ While the concepts were well established, there was still disagreement in some circles as to whether the United States would be driving their development and ushering in an unknowable competitive landscape, or would simply have to be on board or be left behind as the revolution occurred.

⁴ Many examples exist: Army 86 and Army of Excellence are notable ones.

⁵ This was not the first activity to consider significant concept development, albeit past examples may have relied more on revolutionary experimentation than FCS. For additional historical examples, see Glen R. Hawkins and James Carafano, *Prelude to Army XXI: U.S. Army Division Design Initiatives and Experiments 1917–1995*, Washington, D.C.: U.S. Army Center for Military History, 1997.

⁶ For an early discussion on RMA concepts and strategy, see Steven Metz and James Kievit, “Strategy and the Revolution in Military Affairs: From Theory to Policy,” June 27, 1995.

⁷ Training and Doctrine Command (TRADOC), *Force XXI Operations: A Concept for the Evolution of Full-Dimensional Operations for the Strategic Army of the Early Twenty-First Century*, TRADOC Pamphlet 525-5, August 1, 1994.

they represent two phenomena at work in winning what has been described as the information war that has been fought by commanders throughout history.⁸

The concept goes on to describe two main thrusts of the Force XXI “evolution.” The first is the increase in technical means to generate, share, and understand information. The second is how the force will fight when given that new information. The first, therefore, was a result of *evolutionary* integration to network the force with advanced sensors, processors, and communication devices. The second was experimentation on *revolutionary* ways to fight given these information capabilities.⁹

Alongside the rather near-term goals of Force XXI, the Army also took a much further look beyond that force known as the “Army After Next” (AAN). The AAN project was officially started in February 1996 by the Chief of Staff of the Army and the Commander of Training and Doctrine Command to look out 30 years at issues central to the Army: geostrategic setting, evolution of military art, human and organizational issues, and technology trends.¹⁰ The AAN project was looking long-term so that “ideas and a vision of the future will not be constricted by near-term budgetary and institutional influences.”¹¹ The AAN project assumed that by 2010, the successes from Force XXI would be integrated into the force as a stepping stone to the future. As we will see, the specific assumptions made and capabilities discussed throughout the AAN project and those emanating from the broader thinking within the national security domain provided a foundation upon which the much more near-term FCS program was built.

In the end, many of the assumptions within the FCS program about the value and potential for information dominance were engendered by high-level military guidance, and thus not a result of Army thinking alone. The Army’s acceptance of these visions, however, did create challenges and eventual problems as it invested heavily in developing the FCS program.

⁸ TRADOC 525-5, Chapter 1.

⁹ As noted in Adams (p. 12), this combination of evolutionary and revolutionary changes in the context of military adaptation has well-known supporters. Andrew Marshall, Director of the DoD’s Office of Net Assessment, has described it as a combination of both technical development and organizational/operational changes where only in combination does one have a revolution. Thomas K. Adams, *The Army After Next: The First Postindustrial Army*, Stanford, Calif.: Stanford University Press, 2008.

¹⁰ “Knowledge and Speed,” The Annual Report on The Army After Next Project to the Chief of Staff of the Army, July 1997.

¹¹ “Knowledge and Speed,” 1997, p. 1.

FCS Grew Out of the Need to Move the Army into the Future

The Army's concepts and assumptions about the future operational environment and how the Army would fight in that future formed the bedrock for the requirements describing what FCS would be, how it would operate, and what exactly engineers would eventually build. Early requirements represented a confluence of several different streams of official thinking within the Army, the Department of Defense (DoD), and outside national security experts about the future force. At a minimum, this included TRADOC and the wider requirements community, top Army leadership (namely the Chief of Staff of the Army), and the Defense Advanced Research Projects Agency (DARPA) and its industry partners in research and development.

General Eric Shinseki, the Chief of Staff of the Army from June 1999 through June 2003, was the earliest and most outspoken proponent for what eventually became FCS. After he came to office on June 23, 1999, Shinseki ordered an in-depth review of the Army's future requirements.¹² Although Shinseki later downplayed the influence of the Army's recent, dispiriting experience in Operation Allied Force in the Balkans and the recommendations that came out of the review of that operation, the context was inescapable: the Kosovo conflict ended less than two weeks before Shinseki took office.¹³

The experience weighed heavily on those tasked with transforming the service and reversing what many Army leaders feared was a loss of relevance. As the *Washington Post* reported that year, "The Army sat on the sidelines during the successful 78-day air campaign over Yugoslavia, never sending a single unit into combat."¹⁴ The nation's largest uniformed service, as the media framed it, was suffering from an "identity crisis."¹⁵

According to Army thinking in the immediate aftermath of the Kosovo operation, if the service were to engage decisively in such conflicts in the future, it would have to transform itself into a much lighter, agile, mobile, and modern force. Shinseki

¹² Roberto Suro, "Army Plans Lighter, More Mobile Forces; New Armored Vehicles, Recruiting Strategy Part of Push to Change with the Times," *The Washington Post*, October 8, 1999, p. A04.

¹³ Association of the United States Army, "Press Conference [with] Secretary of the Army Louis Caldera and Chief of Staff of the Army General Eric K. Shinseki," transcript, October 12, 1999. Asked by a reporter directly after his AUSA speech how the Kosovo experience influenced his vision of Army transformation, Shinseki replied,

I would say, some influence, but not, in and of itself, just the only fact we considered. We have long thought about how to transform the Army to meet what was obviously, as early as right after the Cold War, what was obviously a changing strategic environment. And over this last seven or eight years, it's really been the Army that's been doing a lot of the heavy lifting in these missions that are short of the warfight, but, nonetheless, are just as intense and energetic. And so we have looked for the opportunity to go after capability we didn't have. Kosovo helped answer some questions.

¹⁴ Suro, 1999.

¹⁵ Suro, 1999.

announced his radical vision of the Objective Force in an address at the “normally staid, even boring,” annual gathering of the Association of the United States Army (AUSA), on October 12, 1999 in Washington, D.C.¹⁶ The speech was pivotal. In it, Shinseki laid out the Army’s shortcomings: heavy divisions had narrow utility and were difficult to move strategically; light forces, though more strategically agile, “lacked staying power, lethality and tactical mobility” once deployed; and the Army’s logistical footprint was “unacceptably large.”¹⁷ To solve these problems, he said, “When technology permits, we will erase the distinctions which exist today between heavy and light forces,” transforming the Army into a “strategically responsive force that is dominant across the full spectrum of operations.”¹⁸

Most notably, Shinseki said that the Army would develop the capability to deliver a combat brigade anywhere globally in 96 hours, a division in 120 hours, and five divisions in 30 days.¹⁹ In addition to agility, the Army would have to become more responsive, lethal, versatile, survivable, and sustainable—broad priorities that TRADOC later translated into key requirements of the eventual FCS program. More fuel-efficient vehicles, more precise and lethal ammunition, lighter armor, “just-in-time” supply delivery systems, and other capabilities would supposedly allow the Army to realize these objectives. It was hoped that the synthesis of these enhanced capabilities would produce a force responsive and dominant at every point on a spectrum extending from humanitarian assistance and disaster relief to major theater wars and conflicts involving the use of weapons of mass destruction. At the onset of the FCS program, most of these objectives remained broad and vaguely defined; some, such as the deployability objective, however, were articulated in measurable terms and stuck out as early, prominent requirements. In any case, the transformation was accepted as a necessary “leap” or revolution in the way the Army would fight, and thus shedding the evolutionary technical changes being executed for the better part of the 1990s.

Not “Out of Nowhere”

The official FCS acquisition program followed a few years after General Shinseki’s 1999 AUSA announcement and reflected his intent closely. The acquisition program was large, complex, and contained goals above and beyond typical acquisition programs—including new ways of interacting with industry, new views of how requirements would be built, and new thinking on how the Army would fight. The goals of FCS, however, did not originate with the 1999 AUSA speech, or the FCS program

¹⁶ Adams, p. 11.

¹⁷ Rowan Scarborough, “Army Chief of Staff Vows Total Force Restructuring; Envisions Swifter, Less Costly Deployments,” *The Washington Times*, October 13, 1999, p. A1.

¹⁸ Scarborough, 1999.

¹⁹ Eric K. Shinseki and Louis Caldera, “The Army Vision: Soldiers On Point for the Nation: Persuasive in Peace, Invincible in War,” October 12, 1999.

itself, but had roots in Army and DoD thinking spanning many years leading to the official start. The central ideas governing how the Army would fight in the future and why a program of the magnitude of FCS was ultimately necessary had a long history, spanning a number of years before the official program was started. Acquisition programs of FCS magnitude do not arise all at once.²⁰

In those years leading up to FCS the Army made many assumptions along the way, which laid the conditions for the FCS program to start. These assumptions were often pulled from interpretations of historical events, long-developed strategic concepts of warfare, and novel analytical products and methods. The assumptions formed the conceptual basis for the program to gain traction and provided the ideas from which the engineering and systems analysis flowed. These inputs to the program—what we term the “initial conditions”²¹ of the program—may also have turned out to be wrong or had profound and unexpected effects on the eventual outcome of the FCS program.

Program Assumptions Were Derived from the Army’s Understanding of the Future Operating Environment

One way to illustrate the conceptual underpinnings of the FCS program is to consider the content and character of the Army’s AAN and later Objective Force annual wargames, where senior leaders and influential stakeholders from across the service discussed and pondered the nature of future Army operations and how the Army might best situate itself in an uncertain future. Many of the original concepts that led to the FCS have their origins in the mid-1990s AAN wargames. The Army’s AAN and Objective Force²² wargames that were conducted from 1997 through the mid-2000s featured a number of key operational concepts and assumptions about the future operational environment that heavily influenced FCS.

These games all utilized a fictional future scenario, generally set in the 2015–2025 time period. The games were at the strategic and operational level, but they would periodically focus on tactical-level issues. Importantly, the games were used to showcase new operational concepts. In the strictest sense, these games cannot be considered “experiments.” Rather, they were opportunities to vet and discuss possible new Army

²⁰ For purposes of this analysis we focused on the post–Cold War Army.

²¹ The term “initial conditions” has its origins in mathematics (boundary value problems) and physics (mechanics). Briefly, a system can have a sensitive dependence on initial conditions where small perturbations in one or more of the conditions can result in widely divergent outcomes. This is not a bad metaphor to test the conditions leading up to the FCS program as we consider the key inputs to the program that may have created the most problems, and what the Army might do to ensure that those same problems are less likely in the future.

²² The Army After Next was the title used for future concept development until General Shinseki became the Chief of Staff of the Army (CSA), at which time the term Objective Force came into use. The term Objective Force included a more definitive view of what the Army of the 2020s would look like.

systems and operational concepts through the development of insights and issues.²³ Their importance in the overall FCS process should not, however, be underestimated.

The output from the games was generally a set of issues that arose during game play. These issues were generally resolved during the game, but analysts from the Training and Doctrine Command Analysis Center (TRAC) and RAND captured the issues and recorded them in various publications.²⁴ Although the purpose of the games was to identify these issues, game sponsors at times were tempted to assert that the games actually validated certain concepts.²⁵

The assumptions made by the Army concerning the future environment were critical to the design and operation of the FCS. Below are some of the most important assumptions that the Army made during the late 1990s about the future operational environment.

Most Conflicts Would Involve High-Intensity, State-to-State Combat

With one exception (a 1998 game set in future Indonesia), the early AAN/Objective Force wargames focused on high-intensity conventional combat with the United States (and its coalition partners) fighting against an aggressive, well-armed regional power. This included future opponents that were either a re-armed Russia or a major regional power such as a state emerging out of the hypothetical union of Iraq and Iran. With the exception of the Indonesia insurgency scenario, there was little emphasis or discussion given to irregular warfare or protracted post-conflict operations. This tendency to focus on high-intensity state-to-state warfare in the 2020–2025 era began to change after the 2004 wargame.²⁶

Nevertheless, the early focus of the wargames and concept development process during the late 1990s was profoundly influenced by the assumption that the dominant feature of the operational environment would be large-scale conventional combat between nations or what had become known within DoD as major regional conflict operations (MRCs).

²³ In July 1998, the then Deputy Chief of Staff for Doctrine at TRADOC, Brigadier General Edward Buckley, forwarded a memorandum to the Army Chief of Staff that described the intent of the game as follows: “[The AAN Spring Wargame] was designed to exercise the dynamics of future warfighting to *help surface the critical issues* and challenges of global operations in the 2021-era” [emphasis added].

²⁴ See, for example, Walter L. Perry, Bruce R. Pirnie, and John Gordon IV, *Issues Raised During the Army After Next Spring Wargame*, Santa Monica, Calif.: RAND Corporation, MR-1023-A, 1999a.

²⁵ See, for example, Robert H. Scales, Jr., *Yellow Smoke: The Future of Land Warfare for America's Military*, Lanham, Md.: Rowman and Littlefield, 2005. Major General Scales writes that “The Army After Next strategic wargames *taught the lesson* time and time again that no degree of strategic velocity could begin to compensate for the advantage offered by forces” [p. 104, emphasis added].

²⁶ At that time, the wargames had become joint exercises with the Army and JFCOM, as it became increasingly apparent that Iraq- and Afghanistan-like conflicts might become the norm for future combat operations for the foreseeable future. These wargames went through multiple changes as “Army Transformation Wargame” and then “Unified Quest.”

Army Forces Must Be Deployed Very Early in a Crisis

A key feature in all of the AAN/Objective Force games was the assumed need to commit ground forces (in particular the Army) very early in a crisis. Most of the early games that had major influence on the early FCS design included a large-scale cross-border invasion by a fictional opponent.²⁷ The notional enemy would usually attempt to rapidly seize all or part of a neighboring country and then, in the words of the TRADOC game designers, “set” his defense. It was assumed that once the enemy had “set,” he would prove to be a much more formidable opponent, since he would now be defending his just-acquired territorial gains in hidden defensive positions and urban areas. Therefore, a fundamental assumption was made that very high-speed deployment and immediate engagement of Army forces was required to preclude the enemy from “setting” into defensive positions. This very important assumption—that decision makers above the Army would be willing to risk early, large-scale commitment of ground forces in rapid offensive operations—was closely related to the operational concepts mentioned earlier.

When Operation Allied Force took place in Kosovo and Yugoslavia in 1999, the Army was criticized for its slow deployment to Albania.²⁸ The Kosovo experience profoundly influenced the Army’s senior leadership and reinforced the perceived need to optimize the future Army for rapid deployment and near-immediate employment. The Army’s view, however, had significant support throughout DoD. The 1997 National Military Strategy, among other defining documents, articulated a clear desire for rapid, decisive operations at strategic distances. It articulated a challenging requirement for the entire military to meet: to “rapidly defeat initial enemy advances short of their objectives” and thereby seize the initiative anywhere in the world.

While the Army has long had the ability to quickly deploy brigade-sized elements of the 82nd Airborne Division by means of U.S. Air Force (USAF) transport aircraft, the AAN/Objective Force goal was far more ambitious, including moving multiple brigades of light mechanized forces by transport aircraft and very fast futuristic cargo ships. In addition to traditional brigade- and division-sized formations, the original

²⁷ While some defense analysts in the 1990s differed over the likelihood of this threat, mechanized assault was widely seen as a particularly dangerous threat. As Air Force officers James Riggins and David Snodgrass wrote in *Parameters* in Autumn 1999,

Although thwarting a conventional mechanized assault is not the most likely form of future warfare for the United States, such an attack poses one of the greatest threats to American interests overseas. This form of warfare is still the mode of choice for countries like North Korea, Iraq, Iran, and other, and will be for the foreseeable future.

Lt Col James Riggins (USAF) and Lt Col David E. Snodgrass (USAF), “Halt Phase Plus Strategic Preclusion: Joint Solution for a Joint Problem,” *Parameters*, Vol. 24, No. 4, Autumn 1999, pp. 70–85.

²⁸ Robert P. Grant, *The RMA, Can Europe Keep in Step*, Paris: The Institute for Security Studies, 2000, pp. 4–5.

AAN concepts also included “battle forces” (roughly speaking, large brigades that were equipped with high-technology armored vehicles weighing less than 20 tons).²⁹

In the early AAN games, each “battle force” was assumed to have several hundred organic Army heavy lift VTOL (vertical takeoff and landing) aircraft with intercontinental range that could contribute to the self-deployment of the force. It was during this period that the term “air mechanization” came into vogue. While the Stryker Brigades equipped with wheeled medium-weight armored fighting vehicles were being fielded in the early 2000s, the Army called for a strategic airlift capacity to deploy a medium-weight brigade anywhere in the world in 96 hours, with the remainder of the division within 120 hours. For medium-weight motorized, much less mechanized, forces these were unprecedented deployment goals compared with typical month-long deployments in previous years.

This desire to enhance strategic deployability heavily influenced the subsequent design of the FCS, since relatively lightweight armored vehicles were needed if large-scale air deployment of Army mechanized units was to be achieved.

Future Army Forces Would Have to Dominate Any Type of Conflict

Defense planners in the middle to late 1990s envisioned rapid force projection as achieving at least two major strategic objectives: first, strengthening U.S. conventional deterrence by vowing near-immediate deployment of heavy-force capabilities to adversaries’ doorsteps in the event of a crisis, and second, if forced to do so, being able to deliver on that promise and, as the 1998 National Military Strategy articulated, “rapidly [defeating] initial enemy advances short of their objectives.”³⁰ Yet the Army also conceded that rapid force projection alone might not ensure victory. In particular, if U.S. forces failed to deter or quickly defeat an adversary, the Army would have to be prepared for any kind of fight, anywhere along the spectrum of conflict. Indeed, urban warfare was a central issue during at least one AAN wargame, during which conventional Red Forces dashed to and fortified themselves in weakly defended key cities in Gulf States before U.S. forces could intervene.³¹ According to the Pentagon’s Joint Vision 2010, a “conceptual template” that the Joint Chiefs of Staff released in 1997, the future force would be optimized for “high intensity conventional military operations,” but it would

²⁹ Early literature dating from 1997 specified a 15–16 ton vehicle. In 1998, the “hybrid force” concept was introduced. This force was to consist of a mix of Force XXI units, strike forces, and notional battle forces. Weights varied from 10 to 40 tons. In April 1999, the Future Combat Vehicle was introduced. This was a family of combat vehicles in the 15–16 ton range. See Walter Perry, Bruce Pirnie, and John Gordon IV, *The Future of Warfare, Issues from the 1999 Army After Next Study Cycle*, Santa Monica, Calif.: RAND Corporation, MR-1183-A, 1999b.

³⁰ Joint Chiefs of Staff, “National Military Strategy, 1997: Shape, Respond, Prepare Now—A Military Strategy for a New Era,” 1997.

³¹ Perry, Pirnie, and Gordon, 1999a, p. 14.

also be able to “dominate the full range of military operations from humanitarian assistance, through peace operations, up to and into the highest intensity conflict.”³²

Yet the ability to do so presumably did not require any additional capabilities beyond those geared toward conventional conflict. As the Army assumed, the same capabilities that would maximize effectiveness in conventional operations, including information superiority, tactical mobility, and precision engagement, would theoretically translate into “full spectrum dominance.”³³ As Army planners gamed out future scenarios during AAN and other exercises, however, they marginalized nonconventional operations relative to high-intensity, state-to-state combat. But the assumption, untested and undervalidated during AAN, that the future force would be inherently dominant anywhere along the conflict spectrum, persisted and eventually flowed into core FCS concepts and early requirements documents.³⁴

Very High Levels of Situational Awareness Will Be Available to Army Forces

Army AAN/Objective Force thinking about “situational awareness” largely mirrored broader DoD assumptions that future U.S. forces would have unprecedented levels of knowledge of their operational environment.

It was during the 1990s that the concept of “network-centric warfare” came into vogue.³⁵ This concept, later called “transformation” by the Army Chief of Staff when he announced the Objective Force concept, is a derivative of the so-called Revolution in Military Affairs (RMA) authored by the DoD’s Office of Net Assessment (ONA) during the same period and subsequently picked up in military writing. Proponents of these concepts claimed that sensor and processor technology was becoming so advanced that in the next few years the “fog of war” in the complex ground combat environment would largely be lifted, even at the lower tactical levels. Some air power advocates claimed that this trend would allow standoff precision fires to achieve unprecedented effects on an opponent who would largely lose the ability to hide.

In the case of the Army, the optimistic assumptions of tactical-level (including down to the company and platoon echelons) situational awareness seemed to enable the use of lightweight FCS vehicles. A favored TRADOC saying during the early 2000s

³² Chairman of the Joint Chiefs of Staff, “Joint Vision 2010.”

³³ Chairman of the Joint Chiefs of Staff, “Joint Vision 2010.”

³⁴ As an early requirements document for the Future Combat Vehicle, later the Manned Ground Vehicle of the Future Combat Systems, stated:

Once engaged, should an opponent not concede early, the Army must be capable of achieving overmatch against any level threat in any region in sustained, decisive combat operations.

U.S. Army, “Draft Mission Needs Statement for Future Combat Vehicle (FCV) Capability,” January 23, 2000.

³⁵ See, for example, Arthur K. Cebrowski and John J. Gartska, “Network-Centric Warfare—Its Origin and Future,” *Proceedings*, U.S. Naval Institute, January 1998, pp. 28–35.

was “see first, decide first, engage first,” a hallmark of the Objective Force.³⁶ Translated, this essentially meant that future U.S. forces would be able to detect their opponents before the enemy found them, and U.S. units would be able to assess the situation quickly and engage the enemy with standoff precision fires before the opponent could direct fire from an ambush position. This much-improved level of situational awareness would, it was claimed, facilitate much lighter armored vehicles (which were, of course, also needed to fit into the VTOL aircraft associated with the air mechanization concept) since heavy armor, always a hedge against tactical surprise, would not be needed as much if at all in the future. A light force that would be much more deployable and yet be as lethal and survivable as a heavy force was so powerful an idea that it became the dominant theme for the Army After Next, soon to be designated the Objective Force. The network was the enabler, but little effort was expended on network architecture at this stage. The dominant interest was on the vehicles.

Army Operations Would Be Supported by Intratheater Air Mobility of Light Mechanized/Motorized Forces

Closely related to greatly enhanced intercontinental deployability of sizable Army forces, the “air mechanization”³⁷ concept involved rapidly maneuvering Army units in-theater via organic heavy lift VTOL aircraft. This concept was first articulated in the AAN “battle forces” in 1997.³⁸ Indeed, the initial AAN concepts envisioned battle forces largely self-deploying over transoceanic distances via organic VTOL aircraft, which would then be used for intratheater operational maneuver. The “air mechanized” concept called for maneuvering Army light mechanized forces into enemy flanks and rear areas transported by hundreds of VTOL aircraft, which, for a number of years into the concept development process, were assumed to be Army aircraft.

The concept of air mechanization was a significant departure from prior Army schemes of maneuver, and with it came considerable technological, operational, and financial hurdles that would need to be overcome. Up until the creation of the air mechanized concept, the Army thought of air mobility of its units in terms of light forces such as the 82nd Airborne Division being transported by USAF aircraft and parachuting near its objective, or the 101st Air Assault Division being transported by Army helicopters. In both cases, the vehicular mobility of the 82nd or the 101st (or other helicopter-transportable Army units) would be limited and would include few if any armored vehicles. The Army had deployed the M-551 Sheridan light tank in the 82nd Airborne Division in the 1970s and 1980s, but had given up on that vehicle as being not very successful.

³⁶ See, for example, “Army Transformation Wargame 2001: Vigilant Warriors,” U.S. Army War College.

³⁷ Sometimes also known as “mounted vertical maneuver.”

³⁸ Walter L. Perry and Marc Dean Millot, *Issues from the 1997 Army After Next Winter Wargame*, Santa Monica, Calif.: RAND Corporation, MR-988-A, 1998.

In contrast, the air mechanized concept envisioned large numbers of light or medium (10–25 ton) armored vehicles, plus their personnel and associated logistics, being moved about the operational area. Each AAN “battle force” was envisioned as having several hundred armored vehicles (which later became the FCS as the concepts were refined), plus the aircraft required to transport those vehicles. This was a truly unprecedented concept for air mobility of light/medium armored forces.

The Army VTOL aircraft would have to be large enough to carry an FCS over operationally significant distances. One of the favorite design concepts to emerge was the very large tilt-rotor conceptually similar to the U.S. Marine Corps (USMC) V-22. Two- and four-rotor designs were considered. Such an aircraft would have to have unprecedented vertical-lift capability, and this requirement became even more challenging as the weight of the FCS started to increase in the 2004–2009 period. Eventually, the Army needed an aircraft with an ability to vertically lift roughly 30 tons. In contrast, the USMC V-22 Osprey can vertically lift only 5 tons.

Since no such aircraft existed at the time of the AAN/Objective Force wargames, the early design requirement was to keep the vehicle within USAF C-130 size and weight constraints (e.g., no more than roughly 20 tons). The C-130 requirement was the surrogate for an eventual heavy-lift VTOL aircraft that would, presumably, be built at some point in the future by the Army or with another service as a joint program. This meant that the deployment of a single FCS-class vehicle would require the allocation of a single VTOL aircraft sortie during aerial assault operations.

Given that a single futuristic FCS-equipped brigade would include 200–300 light armored vehicles, hundreds of large VTOL aircraft would have been required to make the air mechanization concept viable. With the emergence of a more conventionally powered VTOL aircraft, the requirement for transoceanic deployment was relaxed to provide for self-deployment without a full cargo.³⁹

The operational and tactical feasibility of long-distance, large-scale (up to several brigade-sized “battle forces” at a time) aerial maneuver into enemy airspace was based on assumptions that Joint Force and national intelligence systems were capable of finding enemy air defenses which would then be suppressed or avoided. This assumption was also rather problematic because by definition air mechanized forces would have to descend into the envelope of low-altitude air defense systems, at least at the end of their mission as they prepared to debark their troops and vehicles. Because low-altitude air defenses generally do not need emitting radars to find and engage targets (they tend to be optically and infrared guided), they are difficult to locate before they open fire. These systems are also relatively easy to hide because they are generally not very large (e.g., shoulder-fired missiles and 20–35mm anti-aircraft guns). The Air Force and Navy

³⁹ Perry and Millot, 1998, pp. 51–65.

approach to dealing with this threat is to fly above its range. An air mechanized force cannot do that, at least not for the final part of its flight into enemy territory.⁴⁰

Over the few years of the AAN/Objective Force wargames, the air mechanization concept evolved. Instead of one airlift capability to perform both inter- and intra-theater lift, the unit would be delivered to a theater of operation either by strategic airlifters such as a C-5 or C-17, or by very fast ships. Subsequent maneuver within the theater would still be performed with a to-be-developed VTOL-capable aircraft. The air mechanization concept placed high importance on rapid maneuverability over strategic distances, and was a conceptual input to the way future Army forces would fight. With that concept came constraints on what platforms could look like. These very demanding weight and volume requirements profoundly influenced the design requirements for the new FCS family of vehicles.

It should be noted that Stryker Brigade Combat Teams were initially designated Interim Brigade Combat Teams, with the implicit assumption that this design was a temporary bridge in capability leading to the Objective Force brigades that became the FCS program.

Conclusions and Lessons

Conclusions

Army concept development in the 1990s contained significant changes from the way the Army had imagined itself during the prior years of Cold War planning. Future exigencies were envisioned as necessitating broad operational capabilities and rapid strategic deployments. These ideas were built from concepts emanating from across the DoD, with wide support in the military community. The concepts at the time were difficult to dispute.

The Army made many vulnerable assumptions in the leadup to the FCS program about the nature of future combat, the future operating environment, and the perceived needs of the future force. Years of concept development within the Army relied on a set of assumptions that were developed without much technical pushback from Army and other technical communities as to their technical validity. The Army assumed a linear course from 1997 to 2025, with high-intensity conflict at the fore requiring conventional forces capable of defeating large state armies. Irregular warfare was still largely considered a lesser-included capability.

A requirement for rapid inter- and intratheater deployment was established early on, fueled by the Kosovo campaign in which the Army was essentially sidelined. Rapid deployment meant a lighter force. A force that was lighter and more deployable would

⁴⁰ John Gordon IV, David Johnson, and Peter A. Wilson, "Air Mechanization, an Expensive and Fragile Concept," *Military Review*, January–February 2007, pp. 65–68.

also need greatly enhanced situational awareness as its primary means of force protection. Greatly enhanced situational awareness demanded a robust, complicated network. The required technologies grew exponentially as protective and reactive armor was required to absorb enemy attacks as well as leap-ahead technologies in network architecture and design. However, it was even better to avoid attack by gaining the superior situational awareness needed to avoid the enemy and attack him from standoff distances.

Since FCS, however, concept updates and considerations of feasibility have changed in the Army. In late 2009, the Army released two installments of the 525-series publications describing its overarching Capstone Concept⁴¹ and its Operating Concept.⁴² In partial execution of these concepts, the development of future concepts is expected to speed up to better reflect the changing operational environments and provide for a more responsive and adaptable Army. The Director of the Army's Capabilities Integration Center (ARCIC), TRADOC, explained, "This shift [from a five-year concept renewal to a two-year concept renewal] allows for more frequent review of our concepts, our conceptual framework, which reflects the operational environment of today and the future."⁴³

We believe that these are shifts in the right direction. However, a look back at the 1990s concept development, with full knowledge of the events that followed, allows the Army a candid opportunity to consider key lessons from the past when developing "next" concepts.

Lessons

Wargames are good at identifying issues for resolution, but they cannot be taken as validation of concepts. The original intent of the wargames leading up to the FCS program was to highlight issues. But that intent was lost along the way, and the importance and interpretation of wargame events took on much larger meaning in the Army's concept formulation, solidifying the concepts into Army thinking without the due diligence necessary.

Unspecified assumptions can shape the outcomes of wargames. A key aspect of any analytic effort is to clearly identify assumptions being made and understand how important they are to any conclusions later drawn. The importance of the assumptions underpinning the FCS program is unmistakable and underappreciated when interpreting the outcomes of wargames.

⁴¹ Department of the Army, "The Army Capstone Concept: Operational Adaptability: Operating Under Conditions of Uncertainty and Complexity in an Era of Persistent Conflict," TRADOC Pam 525-3-0, December 21, 2009.

⁴² Department of the Army, "The United States Army Operating Concept: 2016–2028," August 19, 2010, TRADOC Pam 525-3-1.

⁴³ As quoted in Kellyn D. Ritter, "Army Modernization, Fiscal Environment Require Acquisition Process Reform," *Army AL&T Magazine*, January–March 2011, p. 30.

Analytic capabilities are important to the success of large, complex acquisition programs. Cuts to the generating force in the 1990s took a harsh toll on the analytic community upon which the Army relies. The development of concepts and the analysis of cost, technical feasibility, risk, and uncertainty during that time were too thinly staffed and not readily heard to affect high-level decisions being made within the Army. As budgets start declining in the near term, and similar decisions have to be made about where and whom to cut within the Army generating force, the lessons from FCS are that technology assessment and analysis capabilities are vital to the effective translation of new force concepts into viable acquisition programs. The proportion of Army budgets allocated to analysis and experiment funding should be increased.⁴⁴

Testing technical and other key assumptions underpinning new Army concepts can identify issues crucial to program success. The Army's new concepts for operating during this period of time were monolithic and without alternatives. Concepts such as strategic and operational maneuverability—"see first, decide first, act first"—which led to a tradeoff of armor protection for intelligence and decision making, suggest that the Army did not have a clear grasp of which technologies were feasible and which were necessary and satisfactory to meet the needs of the future. These concepts eventually found their way into the FCS program with little flexibility. Army wargaming and concept development solidified these concepts rather than testing or questioning them, and the technical community was either left out or ineffective in pointing out the problems with the concepts prior to the FCS program start.⁴⁵ In the end, those concepts were integrated as early requirements for the FCS program, without technical, operational, or organizational support.

Concept generation and exploration would benefit from increased deliberation, input, and consideration from across the Army. The FCS program showed the importance of understanding the technical underpinnings early on and before wide-scale Army adoption or large acquisition investment. Additional work early in concept development will be necessary for some time. This entails the following:

- Increase early interactions among concept developers, the technical community (both the Army science and technology base and industry), and the acquisition

⁴⁴ The Army Acquisition Review also noted that the Army analytic and requirement developments communities are critically short-skilled operations research/systems analysts and cost analysts. *Final Report of the 2010 Army Acquisition Review Chaired by the Secretary of the Army*, Washington, D.C.: Department of the Army, January 2011, p. 63.

⁴⁵ As an example, early Army Science Board findings indicated that technologies were "largely available" for a 2006 engineering and manufacturing development start. See Department of the Army, Army Science Board FY 2000 Summer Study Final Report: *Technical and Tactical Opportunities for Revolutionary Advances in Rapidly Deployable Joint Ground Forces in the 2015–2025 Era, Volume 1, Executive Summary Report*, April 2001, p. 52. Also, the Army Acquisition Review report dated 2011 notes that requirements development "must be collaborative and consistent . . . and include experienced and knowledgeable technologists, cost analysts and operations analysts." Department of the Army, *Final Report*, p. 83.

community to reach consensus on what the art of the possible is from a performance, technical risk, and cost perspective.

- Institute cultural and practical changes in how “games” and “experiments” are used in the Army for concept development—increase the prevalence of alternative points of view and dissenting positions.⁴⁶
- Explore a larger portion of the scenario space during concept development.
- Increase and facilitate the generation—both inside and outside the Army community—of competing conceptual ideas. Ensure that multiple ideas are considered and that robust conceptual answers are eventually found.

⁴⁶ David E. Johnson et al., *Strategic Dimensions of Unified Quest 2005, a RAND Analysis*, Santa Monica, Calif.: RAND Corporation, 2005, pp. 75–86.

Cost, Schedule, and Performance of the FCS Program over Time

The previous chapter chronicled the early history of the FCS, illustrating some of the key influences that shaped its vision and the concepts that flowed from that vision. This chapter turns to the program itself. It shows how the program proceeded, including some major restructuring that occurred. It also details the history of scheduling and associated costs of the FCS program from inception to cancellation. Our conclusion provides a foundation for the chapters focused specifically on requirements generation and evolution, and on program management and contracts.

“System-of-Systems” Interoperability and Unit View Were Key to FCS Planning

The vision for the FCS program was predicated on, among many other capabilities, a much more deployable, yet still survivable and lethal, armored vehicle as a replacement for the Abrams tank. By 1999, the Army’s prior work on lightweight versions of main battle tanks¹ had been ongoing for some years. As an example, the Army’s Future Combat Vehicle (FCV)² was the AAN solution to a more deployable version of the main battle tank. The FCV, as of early 1999, was envisioned as being built from science and technology (S&T) investments and “leap-ahead” technologies,³ with a demonstration planned for 2002 and fielding in 2015–2020. The FCV was therefore a high-tech,

¹ Other lightweight versions had existed for many years, including the Armored Gun System, Light Armored Vehicle–Assault Gun, and Mobile Protected Gun System. Each had its technical and budgetary problems and none was ever fielded, although the Armored Gun System was cancelled due to budget priorities rather than performance or management reasons.

² The intent of FCV had changed over its lifetime as well. Early requirements for a 40-ton version were reduced to around 20 tons as deployability on C-130–equivalent air vehicles, or tilt-rotor advanced air transport, was considered. See “US Army Considers Revolutionary Lightweight Tank,” *International Defense Digest, Jane’s International Defense Review*, Vol. 031, No. 007, July 1, 1998, p. 6.

³ Paul J. Hoeper, “Statement by the Honorable Paul J. Hoeper,” April 20, 1999, p. 8.

revolutionary vision, with an almost 20-year horizon.⁴ In mid-1999, the AAE was clear that the Army would need help ushering in those technologies and would look to partner with DARPA, noting that DARPA “would bring both innovation and cutting-edge technology” required by the Army’s vision.

The FCV, similar to the eventual Future Combat Systems program, in the late 1990s was seen as more than just a vehicle.⁵ A draft “mission needs statement” for the FCV from January 2000 included a system-of-systems view⁶ of the capability. The FCV was envisioned as a component of an Army unit, connected throughout the unit to all other assets by a “seamless tactical network” which would provide for physical and information dominance on the battlefield.⁷ And with the Chief of Staff of the Army’s (CSA’s) vocal interest in making the force more deployable and more capable across the spectrum of war, the timeline for realizing the AAN vision as encapsulated in that program changed radically. The Army became focused on immediate solutions to the problem, incorporating the ideas from the futuristic AAN into the near-term vision.⁸

The importance of the system-of-systems vision for Army fighting units and reliance on information dominance were key enablers to rationalizing the reduced combat weight of the vehicles.⁹ Other enablers for the vision had long histories as well. The commonality in system designs, which was a hallmark of the eventual FCS program, has roots in the Armored Systems Modernization (ASM) program and further back in the Armored Family of Vehicles (AFV) program, both of which contained a concept of commonality within families of platforms to reduce costs and allow for the broad mandates of heavy force capabilities.¹⁰ The family view of vehicles, in those cases chiefly heavy tanks and supporting platforms, was expanded upon in the FCS program as the

⁴ This was similar to an even earlier version (ca. 1995) known as the “Future Combat System”—not plural—which was a follow-on Abrams main battle tank, envisioned at approximately 40–45 tons with advanced capabilities, and a 2010–2015 timeline. For a “winning” design for FCS, see Asher H. Sharoni and Lawrence D. Bacon, “The Future Combat System: A Technology Evolution Review and Feasibility Assessment,” *Armor Magazine*, July–August 1997, pp. 7–13.

⁵ Hoeper, 1999.

⁶ The system-of-systems view within the Army predates the FCV as well.

⁷ U.S. Army, “Draft Mission Needs Statement for Future Combat Vehicle Capability,” January 2000.

⁸ Neil Baumgardner, “Army Studying Options for Near-Term 20-Ton Combat Vehicles,” *Defense Daily*, October 8, 1999.

⁹ The 1999 Army Science Board study, among others, provided operational analyses of the value of information superiority to a lightly armored force, further solidifying the “more than a vehicle” nature of the Army’s putative investment in advance of the FCS program. See Paul E. Funk, *Full Spectrum Protection for 2025-Era Ground Combat Vehicles*, Washington, D.C.: Office of the Assistant Secretary of the Army for Acquisitions, Logistics, and Technology; Army Science Board, 2000.

¹⁰ Eric C. Ludvigsen, “Armor’s Future: From One, Many,” *Army Magazine*, May 1991, pp. 32–38.

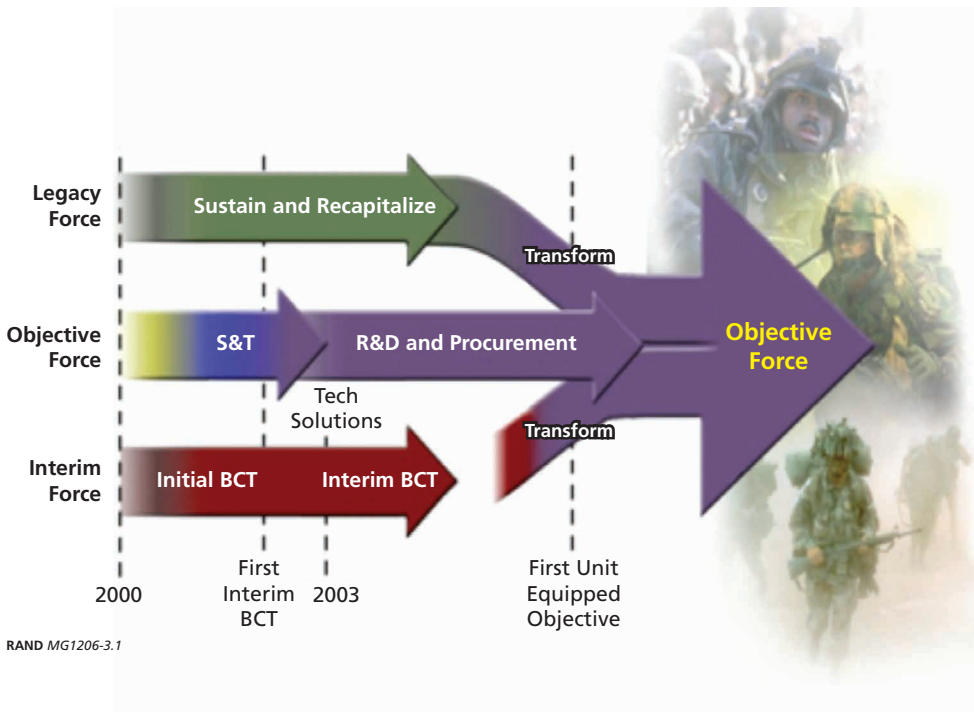
manned ground vehicles were connected with unmanned air and ground vehicles and other technologies in a networked “unit” view.

Initial FCS Schedule Incorporated Immediate and Future Goals

The unit view was a fixture in Shinseki’s vision as he laid out successive Army “forces” that would be developed in subsequent years in parallel, and eventually winnowed to a singular Objective Force (Figure 3.1). Based on the vision from the AUSA speech, the Army would be transformed in multiple, parallel lines that would converge in the not too distant future. A new “Interim Force” would be built immediately, providing off-the-shelf capabilities to portions of the Army in order to train soldiers and grow leaders adept in the future capabilities envisioned. An eventual “Objective Force” would follow that, as revolutionary technologies and revolutionary operating concepts were further developed and refined through S&T and other investments.

The third line would be investments made in the Legacy Force to sustain and recapitalize, with the expectation of eventually replacing it with the Objective Force yet to be built. The Army Modernization Plan at the time spelled out specifically the

Figure 3.1
Army Vision on Reaching the Objective Force



Army's decision with regard to the Legacy Force—that investments would be slowed or curtailed to make way for the future.¹¹ The Army Modernization Plan assumed the risk by underfunding legacy upgrades by \$14B in the 2002 President's Budget, caused in part by the introduction of the Interim Force and the front-loading of S&T in support of the Objective Force.¹²

The Interim Force was based on a lightweight, wheeled vehicle referred to at the time as the Interim Armored Vehicle (IAV). The IAV was intended to ease the transition between what the heavy, Legacy Force could do at that time and what the eventual Objective Force would be able to do in the future. The Interim Force would have some of the same goals as the Objective Force, namely strategic deployability (entailing lower-weight vehicles) and capability for many different types of operations (meaning that it would have some combination of significant fire power, protection, and mobility).

The Army Began Execution of the Vision Immediately

Because of the near-term vision for the Interim Force, the program was under way very quickly. By November 2000, a team led by General Dynamics Land Systems was under contract for producing an off-the-shelf IAV based on the Canadian Light Armored Vehicle (LAV) III.¹³ The program eventually became known as the Stryker program (Figure 3.2), producing its first Stryker-equipped brigade in 2002 and deploying its first brigade to operations in Iraq in late 2003¹⁴—a scant three years after inception.¹⁵ This suggests that a major program, based on upgrading an existing design, can avoid many of the problems associated with a program based on leap-ahead, undeveloped technologies.

The Interim Force based on the IAV became known as the Initial Brigade Combat Team (IBCT)—the unit, or system of systems, that would provide the advance capabilities on the way to the Objective Force. The two early IBCTs were stood up in Fort Lewis, Washington and were expected to be a test-bed and validation for the Objective

¹¹ Headquarters, Department of the Army, "2001 Army Modernization Plan," 2001.

¹² "2001 Army Modernization Plan," p. 45.

¹³ The LAV was an eight-wheeled armored fighting vehicle. Multiple variants of the Stryker vehicle have been produced in the years since inception. The vehicle weight started at about 16 tons and has grown depending on the capabilities added to the vehicle.

¹⁴ The 3rd Brigade of the 2nd Infantry Division deployed from Fort Lewis to Iraq with Stryker vehicles from November 2003 through November 2004.

¹⁵ Since then, the Stryker program has grown considerably, with nearly 3,000 vehicles in the Army and nine Stryker Brigade Combat Teams in the force structure. Nine SBCTs are planned by FY13 at the time of this writing.

Figure 3.2
Stryker Armored Personnel Carrier in Fort Polk, Louisiana



SOURCE: U.S. Government.

RAND MG1206-3.2

Force capabilities as they came online. The plan for the Interim Force was to field brigades through 2008, at which time the Objective Force would begin fielding.¹⁶

The Objective Force concept was predicated on advanced and revolutionary technologies¹⁷ being integrated into the Army in order to change the way the Army fights. Executing the Objective Force vision, therefore, relied on technologies gathered from various places around the Army, DoD, and elsewhere. During the early months prior to the AUSA speech and immediately afterward, the Army technical community identified numerous potential candidates for technology insertion, and budgeted considerable dollars to supporting the S&T needs of FCS.

In November 2000, then CSA General Shinseki commissioned a task force to usher in his vision of transformation. The intent was to execute the vision outlined in his October 1999 AUSA speech and push both the FCS program and other Army activities to the Objective Force end-state—essentially, to build what would be eventually known as the “future force.” Known early on as Task Force Future Combat Systems, and later changed to the Objective Force Task Force (OFTF), it was stood

¹⁶ These timelines were contained in many briefings received by the study team, dated after the 1999 AUSA speech.

¹⁷ This was different from the TRADOC writing mentioned earlier which called for evolutionary development of technologies. General Shinseki, however, was clear in his intent to make a revolutionary “leap” in technologies with the onset of FCS. This is captured well in his speech to the AUSA in October 1999 and reflected in the Program Solicitation (among other places) to industry in 2001 setting a course for the LSI and eventual high-risk technologies that were adopted as part of FCS.

up under the direction of Major General (P) Cosumano on November 1, 2000. There was early pushback from throughout the Army to a separate organization being stood up to lead transformation, and senior leaders were concerned this organization would bypass established organizations to the detriment of the Army.¹⁸ Eventually, a charter was signed in May 2002 solidifying the Objective Force Task Force as an entity to “integrate, coordinate and assess related efforts in the Concepts, Requirements, S&T (including DARPA) and Acquisition disciplines to ensure that the established milestones of the 2003 technology decisions and 2006 Systems Development and Demonstration (SDD) decision are met” (OFTF Carter, p. 2).

Thus, after the AUSA speech laying out the new vision, the Army had many conditions set for action: a grand vision for changing the Army which incorporated multiple ongoing schools of thought, senior leader support for that vision, and a “task force” dedicated to ushering in change. The vision had notable attributes set in place that would affect how the eventual acquisition program would be defined.

First, the eventual program would be very large. The Objective Force would replace the entire force and therefore be a monumental undertaking overshadowing and replacing the rest of the force. Second, it would be highly complex. The notion of building new capabilities around a large Army unit was a complicated and unprecedented undertaking: the networking of platforms, sensors, and soldiers to enable those capabilities and the phenomenology of system-of-systems development in the Army were still vaguely specified and difficult to untangle. Third, it would be technologically revolutionary. The leap-ahead technologies envisioned were not readily identifiable at that moment, but the S&T focus of the effort was apparent from well before the start of the official program. And fourth, it would be very fast. The near-term focus of what had originally been considered part of the Army After Next would entail concomitant technical development, engineering, and integration efforts in order to meet the 2010 goal set by Shinseki.

Acquisition Was to Be Realized Through Multiple Stages

Shown in Figure 3.3 are five phases we use to discuss the progress of the program and highlight the positive and negative actions taken.

Broadly speaking, we use these phases to help explain the major moving parts in the FCS program—each will be explained in greater depth below, but a short description is provided here. The first phase was prior to Milestone B. The Concept and Technology Demonstration (CTD) Phase had two parts; the first started in February 2000

¹⁸ In a letter from then Commanding General TRADOC to the Vice Chief of Staff of the Army, General Abrams noted his concern about the new organization and perceived overlapping responsibilities between it and organizations such as TRADOC and Army Materiel Command. See John N. Abrams, “Memorandum for General John M. Keane, Vice Chief of Staff,” October 26, 2000, p. 3.

Figure 3.3
Timeline for FCS Program

← CTD Phase		SDD Phase →		
Early Development	Reduced Scope	Extension/ Spin-Out	Adjustment Down	Restructuring
<p>1999, Oct: CSA Shinseki speech</p> <p>2000, Feb: Four-team competition led by DARPA</p> <p>2002, Mar: OTA awarded to Boeing for CDT phase</p>	<p>2003: Program transitions from DARPA to Army</p> <p>2004, July: SECARMY/CSA announce program extension</p> <p>2004, Nov: DAB review</p> <p>2004, Dec: ADM</p> <p>2005, Apr: OTA → FAR</p> <p>2005, Jun: MS B follow-up</p>	<p>2006, May: DAB on SO 1 approach</p> <p>2006, June: approval and SDD Exit Criteria for SO 1</p>	<p>2007: "negotiations" to reduce scope</p> <p>2007, Feb: Exp 1.1</p> <p>2007, Oct: EM1</p> <p>2007, Nov: appropriations reflect \$229M cut to FCS</p> <p>2008, June: Spin-outs to IBCTs instead of HBCTs</p>	<p>2009, June 23: ADM cancelling FCS program</p> <p>2009, Sept 25: transition to PEO-I</p>
<p>Various DARPA and Army projects</p>	<p>13+1+1 systems</p> <p>Deferred: FMRV, CLII, CLIII, ARV, IMS</p>	<p>18+1+1 systems</p> <p>Restored all systems</p> <p>Added four spin-outs</p>	<p>14+1+1 systems</p> <p>Deleted: CLII, CLIII, ARV</p> <p>Separated IMS</p> <p>Consolidated to three spin-outs</p>	<p>4 major systems</p> <p>Deleted: MGV (8)</p> <p>Established: E-IBCT</p> <p>PEO-I in charge of integration</p>
	<p>2003, Apr: ORD</p> <p>2005, Jan: ORD Ch 1</p>	<p>2006, Apr: ORD Ch 2</p>	<p>CDD v1.0 (unsigned)</p>	
	<p>2 BCT planned per year</p>	<p>1.5 BCT planned per year</p>	<p>1 BCT planned per year</p>	

NOTE: SECARMY = Secretary of the Army; FMRV = FCS Maintenance and Recovery Vehicle; CLII, CLIII = Class II and III UAV; ARV = Armed Reconnaissance Vehicle; MGV = Manned Ground Vehicle; E-IBCT = Early Infantry Brigade Combat Team; IMS = Intelligent Munitions System.

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with the initial competition contracts between the four industry teams; the second part started with the March 2002 contract signed between DARPA and Boeing (known as the Lead Systems Integrator, the Boeing contract identified a teaming between Boeing and SAIC to perform that role).

In May 2003, the program passed Milestone B and entered SDD with 13 systems identified for development, a reduced number from the 18 systems being considered at the time. This phase lasted until a program re-baseline in November 2005, at which time the full 18 systems were added back into the FCS program, along with four “spin-outs.” Two years later, the program adjusted down to 14 systems and removed one of the spin-outs. Two years after that, the program was restructured significantly. Since then, most of the systems that were continued have been cancelled from follow-on efforts.

Costs and Schedule During Concept and Technology Demonstration Phase: Why So Fast and All at Once?

The original memorandum of agreement (MOA) between DARPA and the Army, signed in February 2000 by the director of DARPA and the Assistant Secretary of the Army for Acquisition, Logistics and Technology (ASA(ALT)), called for a joint project between those entities to develop FCS. DARPA would “be responsible for overall management of the project, including technical, procurement, and security,” and the program manager (PM) would be a commissioned Army officer provided by DARPA. The Army would play a supporting role, integrating the ASA(ALT) (as the primary point of contact) along with the Military Deputy to the ASA(ALT) (MILDEP), various civilian deputy program managers (DPMs), and access to the Research, Development and Engineering Centers (RDEC) directors for technical and other support. In general, the early phases were led by DARPA, with significant Army involvement.

The CTD phase was both a competition for a lead contractor to shepherd the FCS program, and an investment into various technologies being developed within DARPA and the Army, which, at the time, were to be considered as part of the eventual program.

Costs

The MOA provided for a cost-sharing agreement to bring the two parties to Milestone B. Over the period 2000–2005, approximately \$1B would be spent between the two parties, with the Army assuming 55 percent of the costs (see Table 3.1).

During this early phase, DARPA entered into contracts with four industry teams to provide competing designs for the FCS program. The four agreements were awarded May 9, 2000. Table 3.2 indicates the team leaders and shows the contract value. In all cases, the government contributed \$10 million. The industry teams determined how much they would contribute, and that value was reflected in the agreement for each team.

The scopes of the initial agreements were similar. Each included¹⁹ developing system-of-systems (SoS) concept solutions for key areas of mobility, lethality, survivability, deployability, and supportability; at least two force concepts with recommended doctrine and tactics, techniques, and procedures along with associated tradeoff-based rationale assessments; quantifying the performance of the initial force and system(s) concepts and developing data, including the rationale and sources of data pertaining to their force and system(s) concepts; identifying the technologies, missions, and tasks necessary to conduct the range of combat operations, associated tradeoffs, opportunities for preplanned product improvement, technical and schedule

¹⁹ The details are taken from the other transactions (OT) agreements with the various partners: MDA972-00-9-0001 (Boeing); MDA972-00-9-0002 (SAIC); MDA972-00-9-0003 (FoCuS); and MDA972-00-9-0004 (Gladiator).

Table 3.1
Cost Expectations of Early Phases of FCS

Phase	FY00	FY01	FY02	FY03	FY04	FY05	Total
Concept Development, M&S and Surrogate Exercises							
ARMY	12	15	3	0	0	0	30
DARPA	10	15	5	0	0	0	30
Enabling Technologies							
ARMY	0	29	79	72	0	0	180
DARPA	46	46	60	74	0	0	226
FCS Design/Demonstrator							
ARMY	0	0	25	50	114	111	300
DARPA	0	0	25	48	62	15	150
Subtotals							
ARMY	12	44	107	122	114	111	510
DARPA	56	61	90	122	62	15	406
Program Total	68	105	197	244	176	126	916

SOURCE: Original MOA between Army and DARPA.

NOTE: These costs represent the original planned costs as per the February 2000 MOA. There were subsequent modifications to the MOA, but the amounts were kept similar. Quantities are millions of then-year dollars.

Table 3.2
Phase 1 Agreements

Team Leader	Contractor Cost Share	Government Amount
Boeing (Phantom Works)	\$23,299,998	\$10M
SAIC	\$12,830,470	\$10M
Team FoCuS Vision (GDLS, Raytheon)	\$14,000,000	\$10M
Team Gladiator (TRW, LM, CSC, CMU, Battelle)	\$15,461,499	\$10M

risks, interfaces with other organizational elements, and anticipated key component/system performance parameters.

The approximately \$1B associated with the DARPA/Army MOA were not the only funds being invested in FCS (shown in Table 3.1). The Army also bolstered its S&T investments greatly at the same time. The investments were part of an approximate \$3B investment in the FY02 Budget Estimate Submission (BES) “to mature and accelerate FCS technologies such as advanced armor, active protection, multi-role (direct/indirect) fire cannons, compact kinetic energy missiles, hybrid electric vehicle propulsion, human engineering, signature management and advanced electro-optic/infrared sensors necessary for FCS.”²⁰ Early in the program, S&T budget was increasingly allocated in support of the Objective Force (97 percent), with 37 percent of that

²⁰ From SAAL-TT, “Information Paper: Future Combat Systems,” February 5, 2001.

amount specifically tasked in support of the FCS program.²¹ This increase in S&T investment is further described in Chapter Eight.

By March 2002, DARPA and the Army selected a merged team of SAIC and Boeing to lead the next phase of CTD. They were deemed the Lead Systems Integrator (LSI) and the government signed an OTA agreement, Section 845 with Boeing for \$154 million to take the program to Systems Development and Demonstration. The agreement²² was to be for 18 months but permitted a sole-source extension through SDD provided that Milestone B was passed and the government deemed it prudent to carry Boeing forward as LSI.

Schedule

The original “Army After Next” projects pushing for Army transformation called for a long technical gestation period lasting multiple decades, and bringing the Army into the 2020 time frame and beyond with advanced technologies and revolutionary operational concepts. The original FCS other transactions (OT) solicitation to the four contractors in competition required a nearer-term target of 2012 for delivering capabilities to the Army.

FCS started with an aggressive schedule that changed multiple times throughout the program. The MOA between DARPA and the Army in early 2000 proposed a six-year CTD Phase, which would lead to a Milestone B decision in FY06 to bring the program into SDD.²³ At Milestone B, it was expected that the Army would take over formal management of the program from DARPA. The Milestone C decision to move into low-rate deployment was expected in 2008.

The FCS program was known to be a risky endeavor at the time. Then-DARPA director Frank Fernandez publicly noted that the program was high risk with an aggressive schedule, describing it as radical and revolutionary and expressing his expectation that it was likely to encounter both technical and conceptual issues as it progressed.²⁴ This description illustrates that DARPA considered the program somewhat experimental, consistent with the kinds of activities DARPA normally undertakes. The timing of this comment is also instructional: at that time, the FCS program plan included a CTD phase of 5–6 years leading to a Milestone B decision and transition in early FY06. This would change with pressure from within the Army to speed the delivery of the first FCS-equipped brigade.

²¹ Numbers taken from “2001 Army Modernization Plan.”

²² Contract number MDA972-02-9-0005.

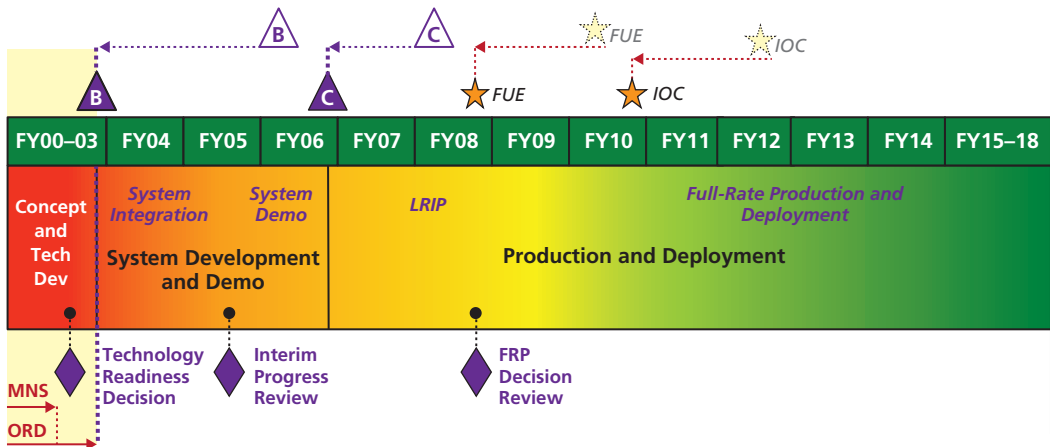
²³ Note that some of the names of the phases per DoD guidance have changed during the FCS program. We use the most recent names for consistency in this report.

²⁴ Kim Burger, “DARPA Chief Warns Army of Risks in Developing Future Combat System,” *Inside the Army*, July 3, 2000.

On September 5, 2001, during a Requirements Review Council (RRC),²⁵ the accelerated schedule was proposed. It moved Milestone B from 2006 to 2003 (see Figure 3.4), as well as speeding up subsequent events in order to have the first unit equipped (FUE) by 2008 and initial operational capability (IOC) by 2010. The briefing included other notable aspects of the program, including expectations of the role and timing of the LSI. In addition to the rapid nature of technology development and demonstration being requested, the briefing also hammers the concurrent nature of the Objective Force endeavor, noting: “The Army needs a ‘systems of systems’ acquisition management approach that will allow for the integration of multiple technologies and systems to be deployed nearly simultaneously” (RRC, 2001, slide 5). This briefing was presented by LTG Riggs (the OFTF lead) and attended by many senior leaders in both the Army and DARPA including the CSA, VCSA, and DARPA director.

By the time of the following RRC on November 1, 2001, planning for the accelerated schedule, which moved Milestone B up by three years to FY03, was already under way. At the November RRC, the Chief Scientist of the Army, Dr. A. Michael Andrews, provided an assessment of the readiness of the FCS technologies to meet the new schedule.²⁶ The assessment was based on activities carried out in the months between the September RRC and the November RRC, which included numerous stakeholders and experts from both within and outside the government. The accelerated schedule

Figure 3.4
Early Schedule Expectations in the FCS Program



SOURCE: Adapted from the September 5, 2001, and November 1, 2001, RRC briefings.

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²⁵ RRCs were set up by the Objective Force Task Force to gather senior leader guidance and approval on transformation issues.

²⁶ A. Michael Andrews, “S&T Assessment and Analysis RRC,” briefing, November 1, 2001.

was eventually accepted by the Army and codified in the original Acquisition Program Baseline as it transitioned into SDD at Milestone B.

Problems Became Clear as FCS Neared Milestone B

The GAO at the time²⁷ was looking closely at the FCS program. In its mid-July 2002 assessment (which was later reiterated a month prior to Milestone B), it was both laudatory and concerned by the prospects of the FCS program. The concerns stemmed from many of the common complaints levied on the program over the years—the fast schedule, technology readiness issues, and a concern for the concurrency within the program, noting that it was “developing multiple systems and a network in less time than DOD typically needs to develop a single advanced system.”²⁸

The GAO’s main findings provided three options: break the large program into more manageable pieces, extend the timeline for entering SDD, or provide more demonstrations of the technology before entering the next phase. In essence, the size, complexity, and novelty of the technologies created concerns from many onlookers. From our many discussions with senior and mid-level people working on the FCS program, it was clear how important meeting that timeline was to the program.

It was also clear how many problems the rapid timeline created. As explained in subsequent chapters, it affected how requirements and technologies developed, and it created many challenges in engineering and architecting the solutions. Other senior officials noted the assurances they received from DARPA senior officials directly, and the general belief many involved in the program shared, that the timeline, while aggressive, was executable.

From our various discussions in this project, it was widely evident that both Army officials and LSI personnel under contract felt significant pressure to meet CSA Shinseki’s original intent to field the unit by decade’s end, thus allowing for little flexibility in dates. The initial operational capability date of 2010 was ambitious for any reasonably sized program; for a large, brigade-sized Army acquisition program representing nearly the entirety of Army modernization itself, that date was profoundly ambitious. Nonetheless, the program moved to Milestone B as scheduled in May 2003 garnering a “pass” by the AAE contingent on various updates.

The Program at Milestone B Left Multiple Issues to Be Resolved

The Defense Acquisition Executive (DAE) approved the first Acquisition Program Baseline (APB) for the Future Combat Systems program on May 17, 2003, following

²⁷ General Accounting Office, *FCS Program Issues*, Washington, D.C.: General Accounting Office, GAO-03-101-0R, August 2003. (The GAO is now known as the Government Accountability Office.)

²⁸ General Accounting Office, August 2003, p. 3.

a Defense Acquisition Board (DAB) review three days prior. The program baseline allowed for the Army to manage the program as a Major Defense Acquisition Program (MDAP) and maintain a single funding line at the “family-of-systems” level.

The acquisition strategy for FCS was to field FCS-equipped brigades in “increments.” The increments provided some flexibility in choosing which technologies would be fielded over time based on technical risks and payoffs. The program also planned on “Unit Set Fielding” to bring those technologies as a set to brigades all at once. The first increment²⁹ as defined at Milestone B reduced the total number of systems from 18 to 14. Those 14 systems as part of the increment at Milestone B are listed in Table 3.3.³⁰ The reductions were a result of available funding, and to make it affordable, systems were deferred and some procurement quantities and training miles were reduced.³¹

At Milestone B, the program passed from the CTD phase into the SDD phase with concurrence by the Defense Department’s Acquisition Executive. The OT, section 845 contract with Boeing, which moved the program into CTD Phase 2, was carried forward and amended to reflect the new goals through SDD. While formally passing Milestone B, the program had a number of items yet to complete. Those items were to be updated at a follow-up meeting in November 2004—about one year later. Those items included numerous updates to certain management plans (technology and other processes) and setting up new organizations and coordinating bodies.

Costs at Milestone B

The FCS Selected Acquisition Report (SAR) is prepared annually by the FCS program and submitted to Congress in accordance with 10 United States Code (U.S.C.) § 2432. The SAR provides the status of all FCS program cost, schedule, and performance, and program unit cost and unit cost breach information, if needed. In this report, we use these estimates to track cost, schedule, and performance of the program.

At Milestone B, the FCS program was estimated at **\$77.8B** (in baseline 2003 dollars), which included \$18.1B in research, development, testing and experimentation (RDT&E),³² \$59.1B in procurement,³³ and \$0.6B in military construction

²⁹ Early increments were defined in the Operational Requirements Document. See “Operational Requirements Document for the Future Combat Systems,” Fort Knox, Ky., April 14, 2003.

³⁰ Note that counting FCS systems is not done consistently across many reports internal and external to the program. Because some of the “systems” have multiple variants, it can be unclear which is deemed a separate system versus just a variant. We will use the nomenclature here throughout this report.

³¹ “Future Combat Systems Army Cost Position,” U.S. Army Cost Review Board Working Group, Executive Summary, May 2006.

³² RDT&E costs include the following: developmental engineering, software, prototype, system test and evaluation, modeling and simulation, system engineering, and program management (government).

³³ Procurement was for 15 brigades’ worth of Increment 1 systems.

Table 3.3
Systems Included in the Program During 2003 APB

#	System	Acronym	2003
1	Mounted Combat System	MCS	X
2	Infantry Carrier Vehicle	ICV	X
3	Non Line of Sight Cannon	NLOS-C	X
4	Non Line of Sight Mortar	NLOS-M	X
5	Command and Control Vehicle	C2V	X
6	Reconnaissance and Surveillance Vehicle	RSV	X
7	Maintenance and Recovery Vehicle	M&RV	
8	Medical Vehicle	MV	X
9	UAV Class I	UAV-CL1	X
10	UAV Class II	UAV-CL2	
11	UAV Class III	UAV-CL3	
12	UAV Class IV ^a	UAV-CL4	X
13	Armed Robotic Vehicle Assault Assault (Light) Recon, Surveillance, and Target Acquisition	ARV-A ARV-A(L) RSTA	X ^b
14	Multifunctional Utility/Logistics and Equipment Countermines Transport	MULE	X
15	Non Line of Sight Launch System	NLOS-LS	X
16	Small Unmanned Ground Vehicle	SUGV	X
17	Intelligent Munition System	IMS	
18	Unmanned Ground Sensor	UGS	X

^a The program chose the Class III/IVb as the variant of the UAV Class IV.

^b The ARV-A(L) was sometimes referred to as a MULE variant, and thus at times this list was considered only 13 of the original 18 systems.

(MILCON).³⁴ These costs represented a significant investment by the Army in the near term. The Army had budgeted \$13B in RDT&E and \$9B in procurement over the FY04–FY09 Program Objective Memorandum, which represented 25 percent of its materiel investments over the POM, and 2.3 percent of the Army's Total Obligation Authority (TOA) for FY04–FY05.³⁵

The unit of purchase for the FCS program was the brigade. Embedded in there were hundreds of platforms and associated equipment that would equip a brigade with FCS technologies. The average cost of procuring a set of FCS equipment for one of the 15 brigades (program acquisition unit cost, or PAUC, in baseline \$2003) was \$5.2B, and the average procurement unit cost (APUC, the cost of just the procurement por-

³⁴ The program used two program elements in the budget: one for the Non-Line of Sight-Cannon (NLOS-C), and one program element (with multiple projects) for the rest of the FCS effort.

³⁵ Department of the Army, Program Manager, Future Combat Systems, *Acquisition Strategy Report Future Combat Systems*, D786-10160-1, May 13, 2003, p. 10.

tion of the total cost) was \$3.9B per brigade. To put this into perspective, Table 3.4 shows Army estimated costs of other brigades (escalated to 2008 dollars) based on 2008 equipment lists³⁶ compared with the costs of an FCS-equipped brigade. Note how the FCS-equipped brigade still utilizes some current equipment in addition to the FCS equipment being acquired.

The higher relative costs themselves—about two to eight times the cost of replaced platforms, and three to four times the cost of a brigade they were planning to replace—were explained in the FCS program as being cost-effective based on the long-term costs of ownership. The commonality in parts and the holistic designs of the systems (in terms of upgradable electronics and power interfaces) was to provide the cost reductions and business case for the FCS program. The life-cycle costs of the program, which in addition to RDT&E and procurement include personnel, operations and maintenance, and costs of ownership, among other things, were **\$149B** at Milestone B.

Schedule at Milestone B

At Milestone B, the very aggressive schedule from the preceding years was kept. To understand the schedule changes in the FCS program, we track a number of key events through the successive program restructurings, quickly described here: Starting with the ORD and Mission Needs Statement, the SoS specification is refined during the SDD phase. The SoS preliminary design review (PDR) provides an early review of designs on their way through the systems engineering and development process. As those designs are further solidified, the SoS critical design review (CDR) provides a

**Table 3.4
Equipping Costs of Various Units (\$B)**

Unit	Total (2008 dollars)	FCS and Key Enablers	Current Equipment
HBCT	\$2.2		\$2.2
IBCT	\$0.6		\$0.6
SBCT	\$1.8		\$1.8
SBCT-Digital	\$2.9		\$2.9
FBCT	\$8.0	\$7.4	\$0.6

SOURCE: Army provided estimates based on DASA(CE) Forces Cost Model.

NOTE: HBCT, IBCT, and SBCT are the Heavy, Infantry, and Stryker variants of Brigade Combat Teams, respectively. FBCT is the FCS Brigade Combat Team.

³⁶ Various assumptions are made to generate these data: FY08 cost of all equipment in each Standard Requirements Code (SRC) as contained in the Consolidated Table of Organization and Equipment (TOE) Update. FCS totals are expected average fully loaded procurement costs over life of program, adjusted to FY08 constant dollars. The results do not include ancillary end items in FBCT 3rd maneuver battalion or other minor TOE changes. Includes FCS Class IV in Combat Aviation Brigades (CABs) allocated to the cost of the BCT, but not other associated support equipment requirements outside BCT formation. Includes Operations and Maintenance, Army (OMA) equipment buys if on TOE.

technical review to determine whether a program can proceed into fabrication, demonstration, and test and can meet stated performance requirements within cost, schedule, risk, and other system constraints.³⁷ The CDR allows for the program to move into some production in order to meet IOC. In the case of FCS, the IOC would have been a battalion-sized element of FCS equipment (a battalion is about one-third the size of a full-up brigade). After additional testing and further production, a full brigade would have been built for initial operational test and evaluation (IOT&E). After the analysis of the IOT&E event to determine whether the systems were meeting requirements and the suitability for production, full operational capability (FOC) could be met with a single FCS-equipped brigade. At that point, the program would move to a full-rate production (FRP) decision, where the Army and other stakeholders would determine whether the remaining 14 brigades should be built. For the FCS program, the major milestones were:

Milestone B:	May 2003
SoS PDR:	December 2004
SoS CDR:	March 2006
Milestone C:	February 2008
IOC:	December 2010
IOT&E:	June 2012
FOC:	December 2012
FRP:	June 2013.

After the FRP decision, the Army planned on producing the 14 remaining FCS-equipped brigades at a rate of one per year (for 2009 and 2010) and two per year for the remaining years until complete in approximately 2017.

First Restructuring in 2004 Increased Systems and Introduced Spin-Outs

Despite unresolved issues, the FCS program changed significantly following an initial Milestone B event in May 2003. On July 21, 2004, the Secretary of the Army, and the new CSA, General Peter Schoomaker, announced that the Army was adjusting the program considerably from the intent of the 2003 Milestone B review.³⁸ The first major change was that the program would begin to “spin out” technologies to the warfighter, in order to be more relevant to the current fights in Iraq and Afghanistan. At the time, four phases of spin-outs were planned starting in FY08, and then three more in FY10, FY12, and FY14. These spinouts would “spiral” FCS capabilities to the current force

³⁷ Definition from www.dau.mil.

³⁸ Selected Acquisition Report (SAR), December 31, 2004, p. 4.

(to include Stryker, Heavy, and Infantry brigades) and run in parallel to the 15 BCTs that would be completely built with FCS technologies.

The “spin-outs” were separate from the initial “incremental” approach of the program. The spin-outs would take individual systems and field them to units. The increments were about setting expectations for brigade-set capabilities based on reduced requirements and numbers of systems. The term “spiral,” used often in the program, was an early name for the strategy, but was changed to “spin-outs” in early 2005. As noted later in the report, the mixing of different incremental strategies was not well understood by all participants and onlookers to the FCS program.

Inclusion of Spin-Outs

The discussion of spin-outs was initiated immediately after Milestone B in May 2003 when the new Chief of Staff, General Schoomaker, took office and indicated his intent to provide FCS capabilities much earlier than originally proposed to help units currently deployed. Discussions on affordability started soon after, and a special update to the Army System Acquisition Review Council (ASARC) by G8 Program Analysis and Evaluation (PAE) on October 17, 2003 provided comments on the affordability of the FCS program, specifying that additional costs would be necessary for spiraling out capabilities to the force which were not then programmed.³⁹

On November 18, 2004, the Defense Acquisition Board directed the restructuring of the FCS program and imposed a requirement to deliver spin-offs of the FCS capabilities to the Modular Brigade Combat Teams (MBCTs). On December 17, 2004, an Acquisition Decision Memorandum (ADM) authorized the Army to better balance current and future force priorities and directed the Army to prepare updated program documentation to articulate the addition of FCS capabilities spin-outs for MBCTs to the delivery of FCS. On November 2005, one year later, a new ADM was signed that re-baselined the program at substantially higher costs and with shifts to the schedule.

The restructuring had significant impacts on management of the program, which are dealt with elsewhere in this report. The restructured program also pushed the Milestone B update that was supposed to happen in late November to June 2005.⁴⁰ The update, however, in the eyes of many officials we spoke with, was unimportant compared to the major restructurings ongoing in the program. The Milestone B decision had been made already, and the program had already officially transitioned to SDD. The updates were “administrative,” with updates to documentation and structures being built. Nowhere in the Milestone B updates were key limitations of the original Milestone B reassessed, including, for instance, the technological immaturity that left many critical technologies less than ready as the program entered Milestone B.

³⁹ “PAED Presentation to Special ASARC 21 October 2003,” October 21, 2003, [FCS ASARC PAED Slides v14 no backups.ppt].

⁴⁰ Selected Acquisition Report (SAR), September 2005.

At that same time, the Army put forth a prioritization for the designated spirals (SAR, December 31, 2004, p. 4). The prioritization was as follows: (1) command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) network, and system of systems common operating environment (SoSCOE), (2) unattended munitions, (3) sensors, and (4) unmanned air and ground vehicles. These were deemed to be the most important and technically ready items for spiraling to deployed units.

The program change was significant. This type of rapid fielding of new technologies to warfighters has recently been the focus of significant efforts with many dozens of organizations involved, including the Rapid Equipping Force, Rapid Fielding Initiatives, and various task forces focused on specific technologies and capabilities to defeat threat adaptations (such as improvised explosive devices). Back in 2003, an Institute for Defense Analyses (IDA) study of the FCS program highlighted several avenues for accomplishing this sort of technology spin-out, noting that such an effort to be taken on by the FCS program might inadvertently take focus away from the original intent—to field FCS-equipped brigades. The IDA study mentioned options:

- provision through the “Modular Units” initiatives
- using the Rapid Equipping Force or Agile Development Center
- ad hoc fielding to units on the cusp of deploying
- working through a then newly established TRADOC division known as “Spirals Division”

While it is unclear what are the “best” means of pulling technologies into the force from the experiences in FCS, the Army has learned how important providing early capabilities to deployed forces can be and since has built significant capabilities to do so.⁴¹

In addition, the FCS program showed how difficult it is to spin out technologies from such a long-term program. Interviews with officials highlighted how the spin-outs took valuable time from certain participants in the program who would otherwise be thinking about longer-term development issues and requirements. Similarly, it was unclear to some working on the program how to deal with the rapid nature of the spin-outs, and whether to treat them as programs of record—with all the attending programmatic requirements that entails—or treat them as “good enough” prototypes to be quickly deployed to soldiers.

In June 2008, the Army decided to accelerate the introduction of spin-outs to the force, and change the location of where those spin-outs would be introduced. The IBCTs would receive the first spin-outs instead of the HBCTs, and they would begin to do so in 2011—three years earlier than expected. Based on ongoing deployments to

⁴¹ See Defense Science Board (DSB), “Fulfillment of Urgent Operational Needs,” July 2009.

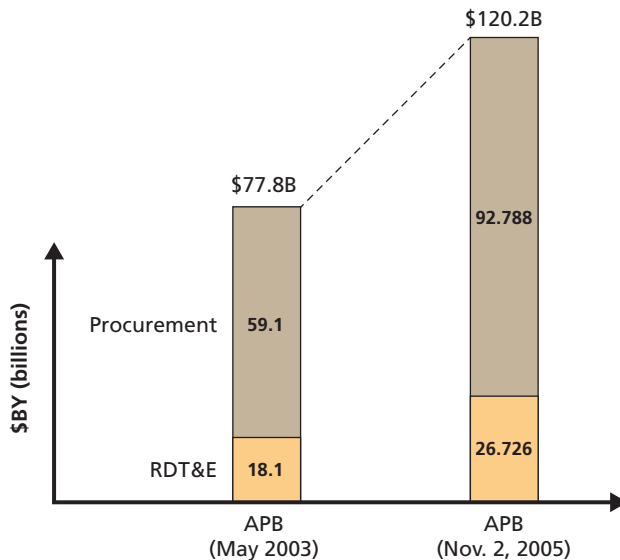
Iraq and Afghanistan, and the significant needs of the IBCTs in those conflicts, they were the natural choice for the first technologies out of FCS. However, once again, this change in spin-out strategy caused turbulence in the program and opened negative perceptions of the Army as they worked to explain the original decision to deploy capabilities to Heavy forces.

The second major change in 2004, in addition to the spin-outs, was that the program would incorporate all 18 technologies (recall that at Milestone B in May 2003, the program had only included 14 of the 18 technologies, and deferred the others for a future time). In addition to the other 14, the Class II UAV, Class III UAV, Armed Robotic Vehicle (ARV)-Assault, ARV-Reconnaissance, and FCS Maintenance and Recovery Vehicle (FMRV) were fully funded in the program to attain the full 18 technologies plus the network. The IMS was also fully funded for integration into the FCS-equipped brigades along with the other systems.

Effects on Cost

The restructured program increased the costs and lengthened the schedule considerably. Because it was a new baseline, the program did not incur a Nunn-McCurdy breach. As shown in Figure 3.5, based on the new baseline set on November 2, 2005, the FCS program costs rose from the 2003 baseline of \$77.8B to a new baseline of \$120.2B. These costs were the result of the restructuring, and subsequent explana-

Figure 3.5
Cost Increases at First Restructuring in 2004/2005



SOURCE: December 2005 SAR for the FCS program.

tions from the program office indicated that 90–95 percent of the cost increases were a result of the Army’s changes to the program.⁴² More specifically, the breakdown in cost changes as explained by the program office is shown in Table 3.5.

The explanation of the cost changes is important to how the FCS program was criticized and subsequently defended in the following years. For one, the majority of the changes were directly attributable to increasing the number of systems in a brigade set of FCS equipment. This did not change the number of units purchased—that remained at 15 brigade sets of equipment—but did change the underlying number of total items being purchased. Thus, the average unit cost increased significantly through this accounting—from an approximate APUC of \$4B per FCS-equipped BCT at Milestone B, to approximately \$6B after restructuring (both in \$2003).

In official SAR submissions, the program attributed the bulk of the cost changes in RDT&E and procurement to “engineering”—59 percent in RDT&E and 71 percent in procurement. Comparison of these attributions to other programs is not straightforward. In a 2008 study,⁴³ cost growth in procurement was largely (51 percent) driven by quantity being purchased across 35 programs evaluated. However, in the case of FCS, the total quantity of BCTs did not change. Instead, the underlying systems within the BCT changed, and these changes were attributed to “engineering” and not to “quantity.”

Life-Cycle Cost Changes

There are multiple cost estimates in the FCS program. The FCS program office produces an official Program Office Estimate (POE), which is its estimate of the costs and is reported in the congressionally mandated Selected Acquisition Reports. In the case of the FCS program, an estimate from the Deputy Assistant Secretary of the Army for Cost and Economics (DASA(CE)) provided the “Army Cost Position” (ACP) (which

Table 3.5
Attribution of Cost Changes as a Result of Restructuring

Procurement Changes		RDT&E Changes	
Deferred systems	32%	Deferred systems	38%
BCT organization	32%	Schedule extension	35%
Platform capabilities	19%	Experiment/maturation	13%
Updated estimates	12%	Spin-outs	8%
1.5 vs. 2 BCTs/year	5%	Updated estimates	6%

NOTE: The costs of hardware for the spin-outs were not included at this time in the program office estimate.

⁴² See “FCS Costs and Cost Estimating,” July 12, 2006, FCS Program Office briefing, slide 9.

⁴³ Joseph Bolten, Robert S. Leonard, Mark V. Arena, Obaid Younossi, and Jerry M. Sollinger, *Sources of Weapon System Cost Growth*, Santa Monica, Calif.: RAND Corporation, MG-670-AF, 2008.

can be the same as the POE) and was used as input to the Milestone B decision and eventual APB that was set in May of 2003.

In parallel to these estimates, the Cost Analysis Improvement Group (CAIG) within the Office of the Secretary of Defense (Program Analysis and Evaluation) group (OSD(PAE)), provided Independent Cost Estimates (ICE) at key points in the program to be compared with the POE and other estimates. At times this estimate was mandated by Congress, but would normally follow POE estimates.⁴⁴ The LSI also produced cost estimates as part of its duties, and often followed closely the program office estimates.⁴⁵

The various estimates of life-cycle costs played a significant role in explaining, justifying, and often times criticizing the FCS program. However, life-cycle cost estimates on such a long-term, novel program are particularly difficult to calculate and uncertain. Army estimates of the yearly operations and support (O&S) costs of the FCS brigade versus other legacy brigades were used to justify the higher upfront costs of acquiring FCS.

In 2006 and after, the difference between DASA(CE) and PM FCS O&S costs were under discussion, and the subject of an Army Overarching Integrated Product Team (OIPT). In 2007, Tank-automotive Command (TACOM) had a parallel assessment of the O&S costs of an HBCT to compare with FCS. The DASA(CE) estimated that the FCS-equipped BCT would be 21 percent higher than an HBCT in O&S costs; the PM FCS/TACOM cost analysis estimated FBCT O&S to be 11 percent lower than HBCT. The differences were explained along several lines, with assumptions on consumables and overhauls providing the largest differences (Figure 3.6).

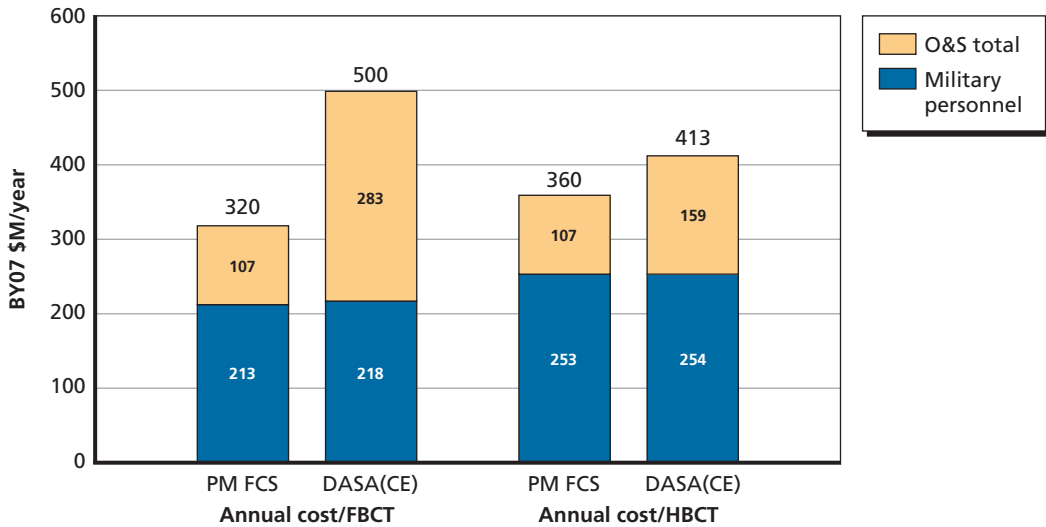
While these numbers were not independently verified by this study team, the intent for FCS was that FCS would provide for long-term shifts in how the Army built and carried its BCTs by using technology and a focus on integration and commonality to reduce overall costs. The outcome of these and other discussions was also clear: that the Army, and the wider DoD community, would need to be in synch for such calculations to be made and widely accepted. The FCS program was a first major step in trying to tie these costs to longer-term considerations, and since then the Army is taking a longer view in O&S consideration of new platforms. The Army is also moving toward a common understanding of O&S cost estimation.

The differences between life-cycle cost estimates from the program office and from outside organizations like CAIG also created problems in program discussions. There were multiple life-cycle and phase-specific costs reported by government and external offices, and the Army had a difficult time explaining the differences in com-

⁴⁴ For instance, in the 2006 National Defense Authorization Act, Congress mandated that the CAIG update their ICE from the Milestone B decision. This update was considerably higher than the program office estimate.

⁴⁵ The study team compared LSI estimates to program estimates from internally generated life-cycle cost estimate (LCCE) cost estimates.

Figure 3.6
Comparison of PM FCS and DASA(CE) Operations and Support Cost Estimates for the FCS Program



NOTES: Army supplied data. BY = base year.
 RAND MG1206-3.6

elling ways. Those numbers were routinely criticized for their differences—some that were actually cost increases, and others that were a result of specific decisions the Army was making. As an example, Table 3.6 shows cost estimates from various phases of the program, which were discussed broadly in GAO reports.

Effects on Schedule

During the 2004/2005 restructuring, the FCS program schedule changed as well. The addition of the remaining technologies and the inclusion of the four spin-outs shifted the objective dates about four years into the future. As will be discussed elsewhere, these program adjustments were major events to the program and caused considerable unrest in management. Table 3.7 contains the changes from the restructuring.

The changes to the schedule were for a variety of reasons, and also included a lengthening of time to build and deploy FCS-equipped brigades. The procurement changed from two BCTs per year to 1.5 BCTs per year with the adjustment in the program. This meant that the last BCT would be produced in approximately 2023.

Other Ongoing Changes

During 2005 and 2006, and during the restructuring, the program continued developing the FCS vision. Functional reviews and early testing of systems were ongoing throughout this period, and technology development continued as well. Several impor-

Table 3.6
Various Cost Estimates of the FCS Program

Category	CAIG Estimate (April 2003)	Milestone B (May 2003 APB)	Post-Restructure (2006 SAR)	CAIG ICE (May 2006)	IDA Estimate (2007)
RDT&E	24.8	18.1	26.4	32 to 44	~ 38
Procurement (acq and ownership)		66.7	100.9	118.7	—
Military construction		0.6	0.6	0.3	—
Military personnel		36.7	57.7	56.3	—
Operations and maintenance		25.9	41.8	87.9	—
Total		149.3	229.5	295 to 307.2	—

SOURCE: Army-provided estimates, GAO-08-408.

NOTE: All costs in \$B 2003.

Table 3.7
Schedule Changes from 2003 to 2005 Acquisition Program Baselines

Date	2003 APB	2005 APB
Milestone B	May 2003	May 2003
SoS PDR	Dec 2004	Aug 2008
SoS CDR	Mar 2006	Aug 2010
Milestone C	Feb 2008	Sep 2012*
IOC	Dec 2010	Dec 2014
IOT&E	Jun 2012	Apr 2016
FOC	Dec 2012	Dec 2016
FRP	Jun 2013	Sep 2016

SOURCE: Acquisition Program Baseline, November 2, 2005.

NOTE: Milestone C was further adjusted in late 2005 after the rebaseline to June 2012.

tant events occurred through that period. For one, the FCS program stationed a brigade at Fort Bliss, Texas, to help evaluate and test new capabilities being built in the FCS program. The brigade, known as the Evaluation Brigade Combat Team (EBCT), would work with White Sands Missile Range (New Mexico) to evaluate early capabilities, not unlike past Army units detailed to do so. This brigade would go on to form a key input to how integration is evaluated and thought about within the Army.

Another major change during this period was to the LSI contract. In May 2005, the ASA(ALT) directed the FCS program to change the contract with Boeing from an OT agreement to a FAR-based contract. This change created unrest in the program and is dealt with in Chapter Seven.

Second Restructuring in 2007 Elicited Deferments and Changes in Some Systems

In the years after Milestone B, the FCS program was under increasing scrutiny. Congressional interest, bolstered by GAO and myriad other audits, became more vocal, eventually playing a role in decreasing funding over multiple years. (A longer explanation of congressional decrements to FCS funding and their increased scrutiny of the program is contained in Appendix B.) The decrements over FY05 through FY07 were highlighted by the FCS program as being instrumental in schedule changes and the eventual program restructuring in 2007.

A January 11, 2007 memo from the Army's Acquisition Executive, Hon. Claude Bolton, spelled out the Army's restructuring of the FCS program. In it, the AAE explained succinctly the reasoning behind the restructuring:

Based on competing priorities and needs, the U.S. Army has directed cuts or adjustments to the current FCS baselined program across the Future Year's Defense Plan and Extended Planning Period. These directed cuts or adjustments are strictly budget driven and are not due to poor contractor performance issues or problems.⁴⁶

The competing priorities included the significant Army deployments to theaters in Iraq and Afghanistan as part of Operation Iraqi Freedom and Operation Enduring Freedom, and the needs of those forces compared with the trajectory that modernization was on at the time. The adjustment called for the deferment of some FCS systems, and changes in quantities of some of the remaining systems. Those changes are shown in Table 3.8.

Changing the Number of Program Elements

Starting in FY08 as well, the structure of the RDT&E program elements supporting FCS would be changed in accordance with congressional direction. Prior to this period, the FCS program worked under three program elements: one for Armored Systems Modernization (ASM), with six projects; one for the Non Line of Sight Cannon (NLOS-C); and one for the Non Line of Sight Launch System (NLOS-LS). From FY08 onward, the program was directed to split the ASM program element into six separate program elements, roughly aligned with aspects of the systems plus integration: Manned Ground Vehicle (MGV); SoS engineering and program management; UAV; UGV; UGS; and network hardware and software.

The FCS program had started in 2003 with a single program element. The thinking behind this choice, according to senior officials, was to provide the most flexibility in the allocation of resources within the system of systems. Under a single PE, the pro-

⁴⁶ Claude M. Bolton, Jr., "Memorandum for Program Manager, Future Combat Systems (Brigade Combat Team)," January 11, 2007.

Table 3.8
FCS Systems at 2007 Restructuring

#	System	Acronym	2007	
1	Mounted Combat System	MCS	X	
2	Infantry Carrier Vehicle	ICV	X	
3	Non Line of Sight Cannon	NLOS-C	X	
4	Non Line of Sight Mortar	NLOS-M	X	
5	Command and Control Vehicle	C2V	X	
6	Reconnaissance and Surveillance Vehicle	RSV	X	
7	Maintenance and Recovery Vehicle	M&RV	X	
8	Medical Vehicle	MV	X	
9	UAV Class I	UAV-CL1	X	Decreased in quantity
10	UAV Class II	UAV-CL2		Made an objective requirement
11	UAV Class III	UAV-CL3		Made an objective requirement
12	UAV Class IV	UAV-CL4	X	Increased in quantity
13	Armed Robotic Vehicle Assault Assault (Light) Recon, Surveillance, and Target Acquisition	ARV-A ARV-A(L) RSTA	X*	Deferred and returned to tech base Increased in quantity Deferred and returned to tech base
14	Multifunctional Utility/Logistics and Equipment Countermine Transport	MULE	X	Decreased in quantity
15	Non Line of Sight Launch System	NLOS-LS	X	
16	Small Unmanned Ground Vehicle	SUGV	X	
17	Intelligent Munition System	IMS		Deferred
18	Unmanned Ground Sensor	UGS	X	Increased in quantity

NOTE: *ARV-A(L) is at times considered a MULE variant, thus making 14 systems.

gram could move money as necessary to meet the overarching needs of the SoS without having to justify individual allocation of funding across systems. As time went on, the program had systems pulled out from under that element and placed into new program elements. The first two were the NLOS-C and the NLOS-LS, which had special circumstances—the NLOS-C itself was deemed a special interest program by Congress and given specific fielding instructions, such as having to be fielded by FY10.

By 2008, given Congress’s increased interest in FCS, there was a desire to split the program up further to increase awareness and control of individual actions ongoing in the program—hence, the increase to eight total program elements. To some within the program, this was contrary to the intent of FCS and ran counter to the flexibility that a system of systems should have in making resource decisions.

Costs at 2007 Restructuring

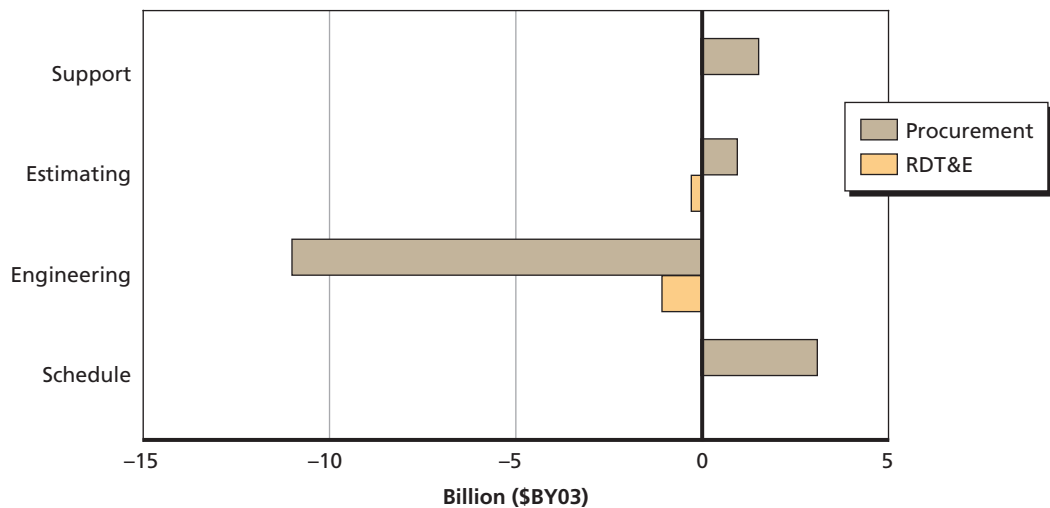
The costs changed marginally with the 2007 restructuring. The total program costs went from \$120.2B to \$113.2B (both in FY03 dollars) at the same time as about one-

quarter of the total systems had been dropped from the program. There was little explanation at the time as to how the program could change the program content so radically and still meet the lofty capabilities that FCS was to bring. This lack of clarity was brought up by the GAO as such: “The Army’s \$160.9B cost estimate for the FCS program is largely the same as last year’s but yields less content as the number of FCS systems has since been reduced from 18 to 14.”⁴⁷ Even with those major changes, the program was large enough—and flexible enough monetarily—to keep costs almost neutral. There were rather significant swings in individual SAR cost categories (as shown in Figure 3.7) attributable to the new, restructured program.

Decreases in program cost from engineering changes were attributed to the reduced number of systems, partially offset by the increase in quantity of some of the other systems. Costs having to do with “schedule” arose from changes to the rate at which FCS-equipped brigades would be procured. This changed to one BCT per year, starting in 2014 and extending through 2028 (recall the 2005 stated rate was 1.5 per year, ending in 2023). The other cost increases were marginal and arose from changes in estimation and costs of software support.

The changes in rate had profound effects on the long-term procurement schedule of FCS. The 2007 along with the 2004/2005 restructurings extended the final produc-

Figure 3.7
Attribution of Cost Changes from 2003 Through 2006



SOURCE: FCS Selected Acquisition Report from 2006.

RAND MG1206-3.7

⁴⁷ Government Accountability Office, *Defense Acquisitions: 2009 Is a Critical Juncture for the Army’s Future Combat System*, Washington, D.C.: Government Accountability Office, GAO 08-408, March 2008.

tion schedule almost ten years, changing the profile in significant ways. The outyear program estimates for procurement in 2003, 2005, and 2007 are shown in Figure 3.8 along with the number of systems the program would include in each case, and total procurement estimates.

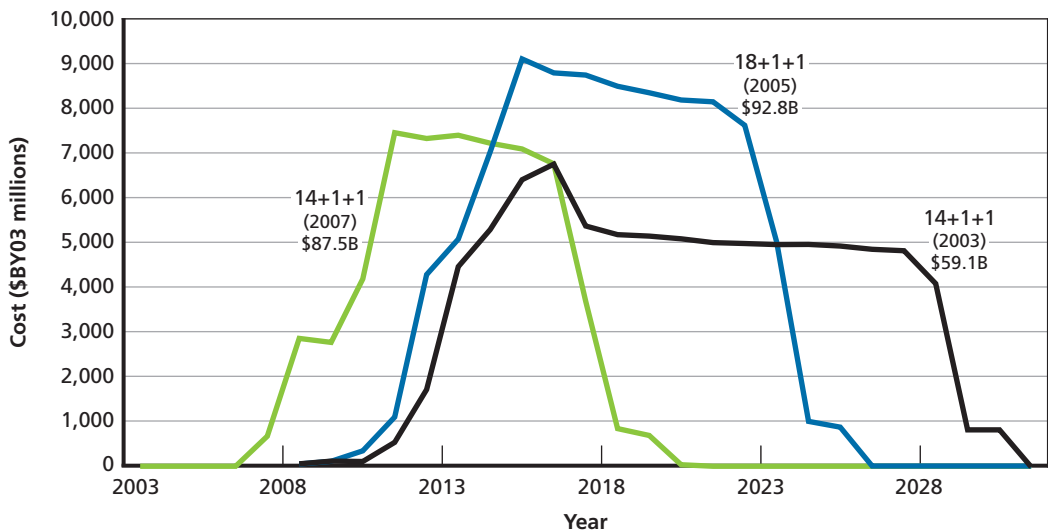
Schedule at 2007 Restructuring Incurred a Nunn-McCurdy Breach

A confluence of decrements to the program and the changes to the systems moved the schedule further out from the November 2, 2005 APB, adjusting five to eight months in each event (Table 3.9). The resulting shifts in schedule incurred a Nunn-McCurdy breach in schedule. The details of the breach were being worked out in 2008. While no SAR was submitted in 2008 for the FCS program, because the program was being considered for restructuring in 2008 and then finally cancelled in 2009, the breach was never followed up.

2009 Cancellation

On April 6, 2009, in a five-page prepared speech, Secretary of Defense Robert Gates outlined a number of major changes that DoD was recommending be adopted. He

Figure 3.8
Estimated Procurement Funding in 2003, 2005, and 2007



SOURCE: Selected Acquisition Reports for FCS from stated years.
NOTE: Procurement costs are shown, not total program costs.

Table 3.9
Schedule Changes from 2003 to 2007

Date	2003 APB	2005 APB	2007 SAR
Milestone B	May 2003	May 2003	May 2003
SoS PDR	Dec 2004	Aug 2008	Apr 2009
SoS CDR	Mar 2006	Aug 2010	Apr 2011
Milestone C	Feb 2008	Sep 2012	Apr 2013
IOC	Dec 2010	Dec 2014	Aug 2015
IOT&E	Jun 2012	Apr 2016	Sep 2016
FOC	Dec 2012	Dec 2016	Aug 2017
FRP	Jun 2013	Sep 2016	Feb 2017

SOURCE: FCS Selected Acquisition Report from 2007.

covered how DoD would address the people, finding a permanent institutional home for the ongoing changes in how warfighters are supported, changes to major conventional and strategic modernization efforts, and broad changes to reflect acquisition and contracting reform. It was in the final topic that FCS was listed, last among six other changes. FCS would be “restructured,” and the vehicle component cancelled and reissued.

Among his reasons for cancelling the FCS program were the following:

- “significant unanswered questions concerning the FCS vehicle design strategy”
- “FCS vehicles—where lower weight, higher fuel efficiency, and greater informational awareness are expected to compensate for less armor—do not adequately reflect the lessons of counterinsurgency and close quarters combat in Iraq and Afghanistan”
- “current vehicle program, developed nine years ago, does not include a role for our recent \$25B investment in the MRAP vehicles”
- “troubled by the terms of the current contract, particularly its very unattractive fee structure.”⁴⁸

The FCS program was effectively cancelled. A following June 23, 2009 ADM from the Defense Acquisition Executive (DAE) formally cancelled the program, and a September 25, 2009 memo⁴⁹ from Dean Popps, the acting ASA(ALT), notified the program of its name change from the Future Combat Systems (BCT Modernization) program to Program Executive Office, Integration. In the latter memo, the PEO-I mission was described as including development, integration, fielding and support of

⁴⁸ Robert M. Gates, “Defense Budget Recommendation Statement,” U.S. Department of Defense, Arlington, Va., April 6, 2009.

⁴⁹ Dean G. Popps, “Memorandum for Program Management Office, Future Combat Systems (Brigade Combat Teams), Warren, Mich. 48397,” dated September 25, 2009.

selected capability packages, and housing of initial efforts for the Ground Combat Vehicle (GCV).⁵⁰ PEO-I was responsible for the Early IBCT program (E-IBCT), which contained those capability sets—largely a result of FCS developed technologies.

The June 23, 2009 ADM signed by the DAE mandated that the Army transition to a modernization plan consisting of multiple integrated Major Defense Acquisition Programs (MDAPs) that covered the production and fielding of the first seven E-IBCT sets. Originally, the E-IBCT Increment 1 included the following technologies, largely a result of the FCS program:

- NLOS-LS
- T-UGS
- U-UGS
- Class 1 UAV
- SUGV
- Network integration kit
- JTRS Ground Mobile Radio

As will be discussed in later chapters at length, only a few of these exist in development today. The last SAR submitted in December 2007 on the FCS program had the program at \$11.3B spent. Estimates since then have been around \$14B spent in the FCS program at the time of its cancellation.

Conclusions and Lessons

Conclusions

FCS was set up originally with attributes unlike all past Army acquisition programs. It was large, complex, novel, and expected to be accomplished in a short period of time. It was also a new method for ushering in large-scale Army change—namely, by going through an acquisition program to bring in new concepts, new technologies, and a newly integrated brigade formation all at once. Because of these attributes, the program experienced significant turbulence throughout its history.

Lessons

From these beginnings, and through charting the cost, schedule, and performance over time, a number of lessons are apparent.

Senior-level involvement can significantly motivate an acquisition effort. Early support for the FCS program was significant from the highest levels within Army leadership and aided in calling a large and complex program into existence quickly.

⁵⁰ GCV eventually moved to PEO (Ground Combat Systems) about a year later.

The drive to move FCS forward permeated the program, as pressure mounted to meet early timelines and aggressive requirements. In the end, the senior-level involvement was both good and bad for the program, negatively affecting its ability to flex in light of information about technological challenges (Chapter Six will go into more detail on this point).

Major program shifts can cause significant turbulence and erode support for an acquisition program. The FCS program experienced turbulence as a result of multiple major Army decisions to restructure it as knowledge was gained and as operations in Iraq and Afghanistan evolved. The program was restructured two times in significant ways, changed contract types, and added “spin-outs,” all of which made more difficult an already ambitious acquisition program. These shifts, and others, made the FCS program difficult to understand and tough to manage, and in many ways sacrificed internal and external support for the effort.

Cost estimations can be highly uncertain in large, novel programs and subject to various interpretations that can undermine program support. Cost estimation for such a large, complex program was challenging, especially in terms of the software, integration, and life-cycle components. That can lead to disparate estimations, inherent difficulty in determining affordability, and uncertainty among those who develop Army budgets and programs.

Spin-outs are a difficult proposition to be integrated into an acquisition program midstream. The spin-outs in FCS were to capitalize on near-term successes in support of ongoing operations. While the idea was correct, the execution was hampered by unclear guidelines and changing intent.

Large, system-of-system acquisition programs take time. The FCS program, while perhaps remaining a unique acquisition experience for years to come, was progressing slowly compared with the milestones and showed how long such major undertakings can take. The pressure to meet early, aggressive, and unrealistic timelines ultimately forced scheduled events to be moved significantly into the future if the program were to continue.

How the Army Generated Requirements for the Future Combat Systems

The prior chapter provided an overview of the major events of the FCS program, from concept to cancellation. This chapter describes how the Army generated the requirements for the FCS and how they developed over time. The requirements story is relatively complex. To do it full justice, we have divided the discussion into two chapters, this one and the one that follows. Each chapter, however, presents conclusions and lessons that are relevant to the material discussed in the chapter.

This chapter starts from the beginning of the process, tracing concepts and requirements from the Army's original vision for FCS. It then examines how the Army singled out C-130 transportability as a non-negotiable requirement, and how concepts and other requirements subsequently evolved around this central constraint. It next explores the history of the cross-command group that the Army stood up to manage requirements, its successful design of integrated concepts, and its less successful development of integrated operational requirements. Appendix C provides a description of the data and methodology used for our work on FCS requirements, as the topic posed several unique challenges.

The FCS program generated by far the largest and most complex set of requirements in the Army's history. For the first time, the Army was designing an entire brigade from the ground up, based on a revolutionary system-of-systems concept whereby advanced networking technologies would theoretically enable dozens of manned and unmanned systems to achieve unprecedented levels of interoperability and tactical coordination. Combat developers were challenged to develop these capabilities in a radically compressed time frame and at a time when the Army was engaged in two wars that strained resources and challenged fundamental notions about how the Army would fight.

While the extreme magnitude of the challenge that Army combat developers faced has frequently been overlooked in historical accounts of the FCS program over the years, it was not lost on them at the time. Context, though not a form of vindication, is important to understanding why the Army developed the requirements in the way that it did and why, in some cases, it fell short of what it needed to do. At the

same time, it also helps frame the history of requirements in the FCS program less as a squandered effort and more usefully as a series of practical lessons that the Army can absorb as it pursues acquisition programs of similar scale and complexity in the future.

What Role Did Requirements Play?

In theory, at least, requirements describe how the Army should generate its force structure to achieve operational concepts that meet the future functional needs of the military.¹ The process begins with broad strategic guidance, such as the need to be able to achieve dominance across the full spectrum of conflict, and eventually narrows to precise engineering specifications that describe exactly what should be built, how technologies should interoperate, how many ounces subcomponents should weigh, and so forth. In some cases, requirements are intended simply to evolve the force structure incrementally, such as enhancing existing systems with new technologies, or to fill critical capability gaps. This was the Army's approach, for instance, when it fielded Mine Resistant Ambush Protected (MRAP) vehicles to troops in Iraq and Afghanistan in order to improve force protection against improvised explosive devices (IED).

With FCS, however, the Army sought to introduce far-reaching, revolutionary operational concepts. Its requirements therefore called for cutting-edge, futuristic technologies that the Army's strategic planners in the late 1990s assumed decades of scientific progress would enable by 2025. Any acquisition program faces the dual risks that the future capabilities envisioned today may not meet the actual operational needs of tomorrow, and that technological progress simply may not occur as quickly as anticipated. The longer the timeline, the more uncertain the future becomes, which amplifies the first risk; but with more time for technology to mature, in some ways, a longer timeline also dampens the second risk.² For FCS, which began with a decades-long horizon, the risk of future irrelevance was relatively high; by the same token, technical risk was originally thought to be quite low, since technology had a long time to mature. As the program timeline shortened, however, technical risk rose sharply, but neither operational concepts nor requirements evolved to fit more immediate functional needs and reduce the risk of irrelevance.

For these and other reasons, FCS faced a storm of criticism from Congress, auditors, and the wider defense community, which identified a more or less common set of shortcomings in the program's requirements. While our assessment supports some of these earlier verdicts about the FCS requirements, it takes the data, based on unprec-

¹ U.S. Army, "How the Army Runs: A Senior Leader Reference Handbook, 2009–2010," Carlisle, Penn.: U.S. Army War College, 2009, p. 10.

² As the Army notes in its guidebook for senior officers, there is often tension between long- and near-term capability requirements, and "The processes that develop operational units often frustrate those who need the capabilities in the near term." U.S. Army, "How the Army Runs" 2009, p. 14.

edented scrutiny of multiple layers of requirements documentation, interviews with program managers, engineers and requirements developers, and other official program materials, as the principal starting point for analysis. It thus introduces important nuance and additional findings to the history of the FCS program. The existing body of conventional wisdom about the FCS requirements, however, is important to summarize at the outset.

The first, widely agreed-upon flaw in requirements was that FCS was optimized for “conventional combat operations against a mechanized force in relatively open terrain.”³ Yet as unconventional conflicts in Afghanistan and Iraq dragged on, the validated need for such a conventional force became increasingly doubtful.⁴ Second, there was inherent and ultimately unresolved tension between small and light systems key to meeting deployability requirements, and survivability and lethality requirements that put pressure on the size and weight of the systems.⁵ The most well-known example of this is the C-130 requirement, which this chapter will explore in depth. The operational concept’s reliance on thinly armored vehicles to allow for high-volume strategic lift and rapid intratheater deployment via C-130 aircraft ran counter to the rising operational need for more heavily armored vehicles, such as MRAPs, to protect soldiers from IEDs. This gets to the third commonly cited critique of the FCS requirements, which is that the requirements were not properly evaluated for technical feasibility, and thus were unrealistic and ultimately unrealizable.⁶ A related, fourth problem in the FCS requirements, which the GAO reported consistently in its audits of the FCS program to Congress: that system-level requirements, because they were not adequately defined or supported by technical analysis, were unstable and continuously in flux.⁷ As the GAO reported in May 2006, “system-level requirements are not yet stabilized and will continue to change, postponing the needed match between requirements and resources,” and that the program was not expected to stabilize requirements until five

³ Andrew F. Krepinevich and Evan Braden Montgomery, “Correcting Course: The Cancellation of the Future Combat Systems Program,” CSBA Backgrounder, Washington, D.C.: Center for Strategic and Budgetary Assessments, July 2009.

⁴ Krepinevich and Montgomery, 2009; Kevin P. Reynolds, “Building the Future Force: Challenges to Getting Military Transformation Right,” *Contemporary Security Policy*, December 2006, pp. 449, 453 (cited in Krepinevich and Montgomery, 2009).

⁵ Government Accountability Office (GAO), “Issues Facing the Army’s Future Combat System,” Letter to Representative Curt Weldon with attached briefing, GAO-03-1010R, Washington, D.C., August 13, 2003, p. 23.

⁶ GAO, August 13, 2003; Krepinevich and Montgomery, 2009; Reynolds, 2006.

⁷ Paul L. Francis, “Improved Business Case Key for Future Combat System’s Success,” Testimony before the Subcommittee on Tactical Air and Land Forces, Committee on Armed Services, U.S. House of Representatives (GAO-06-564T), April 4, 2006, pp. 5–8; also cited in Andrew Feickert, *The Army’s Future Combat System (FCS): Background and Issues for Congress*, CRS Report for Congress, Washington, D.C.: The Library of Congress, May 2006, p. 11.

years after it should have, when it passed Milestone B in May 2003.⁸ While this is true in some respects, instability was not necessarily the defining feature of the FCS program's requirements. In fact, excessive stability, or inflexibility, of certain requirements, particularly high-level ones, posed an equally serious problem to the program.

Genesis and Generation of FCS Requirements

While FCS did not gain momentum as an acquisition program until after September 11, 2001, the basic conceptual framework was established before 9/11 transformed the U.S. strategic outlook. The foundational ideas for FCS began germinating in Army planning circles in the late 1990s, particularly during the Army After Next (AAN) wargame cycles, which TRADOC launched in 1997 in order to explore new warfighting concepts and capabilities out to about the year 2025.⁹ The wargames and associated studies began to focus attention on the need for rapid, strategic deployment, intratheater tactical maneuver, and radically enhanced situational awareness, lethality, and sustainment capabilities. The unprecedented deployment capabilities would limit the combat vehicles' weight. So FCS would, it was assumed, leverage revolutionary sensor and network technologies of the future to be as survivable, lethal, and maneuverable as much heavier tanks, like the M1 Abrams tank, which weighed more than three times (60 tons plus) the objective weight of the FCS Manned Ground Vehicles (MGV).

Difficult Deployability Requirements Were Inserted Early into Operational Concepts

Chief of Staff of the Army General Eric Shinseki articulated the need for state-of-the-art, leap-ahead transportability capabilities in an October 1999 speech to the annual meeting of the Association of the United States Army.¹⁰ In the speech, Shinseki introduced the Army Vision, a strategic plan to transform the U.S. Army that became a central foundation for FCS concepts and top-level requirements. At the core of Shinseki's

⁸ Francis, 2006, p. 8.

⁹ "Army After Next" briefing, TRADOC, 1997, quoted in John Matsumura et al., *The Army After Next: Exploring New Concepts and Technologies for the Light Battle Force*, Santa Monica, Calif.: RAND Corporation, DB-258-A, 1999. However, an interview subject explained that the program's initial intentions were much more modest than what it became. The original idea was for AAN to be a platform for engaging senior Army leaders in a strategic conversation about the future, although it quickly focused on force structure and operational design, instead. (Interview with former program official, January 18, 2011.)

¹⁰ Eric Shinseki and Louis Caldera, "The Army Vision: Soldiers On Point for the Nation . . . Persuasive in Peace, Invincible in War," speech to Association of the United States Army (AUSA), October 12, 1999, reproduced in Statement by General Eric K. Shinseki on Status of Forces to House of Representatives Armed Services Committee, October 21, 1999.

vision for the future force was an “array of deployable, agile, versatile, lethal, survivable, and sustainable formations.”¹¹ As Shinseki explained in the speech:

With the right technological solutions, we intend to transform the Army, all components, into a standard design with internettted C4ISR packages that allow us to put a combat capable brigade anywhere in the world in 96 hours once we have received execute liftoff, a division on the ground in 120 hours, and five divisions in 30 days.¹²

In order to do so, he explained, “We will look for future systems which can be strategically deployed by C-17, but also be able to fit a C-130-like profile for tactical intratheater lift.”¹³ Achieving this vision was potentially to involve developing armored vehicles with “50–70 percent less tonnage” than current vehicles, figures that appeared again, almost verbatim, in a number of subsequent requirements documents and briefings over the next several years.¹⁴ The vision, as Shinseki emphasized, was revolutionary rather than evolutionary. Subsequent requirements documents, in fact, dismissed other families of lightweight vehicles existing or under development elsewhere in the world largely because they were based on “incremental and relatively modest technological improvements,” rather than revolutionary, leap-ahead capabilities intended to achieve the FCS vision.¹⁵

Early Requirements Were Based on the Army Vision

The goals that Shinseki laid out, meanwhile, were not only operationally but also technically ambitious. Moreover, the C-130 transportability and 96-hour deployability thresholds stood out as concrete, high-level performance requirements, more narrowly defined than any other broad, strategic objective in the Army Vision. Unlike the agility, versatility, lethality, and other objectives for the future force that Shinseki described in the Army Vision, he articulated deployability in terms of explicit, quantifiable metrics, which were reproduced in nearly every pre-Milestone B operational concept and requirements document that followed.¹⁶

¹¹ Shinseki and Caldera, 1999.

¹² Eric K. Shinseki, Address to the Eisenhower Luncheon, 45th Annual Meeting of the Association of the United States Army, October 12, 1999.

¹³ Shinseki, Address to Eisenhower Luncheon, 1999.

¹⁴ Shinseki, Address to Eisenhower Luncheon, 1999; A. Michael Andrews, “Future Combat Systems (FCS) Industry Day,” unpublished briefing, Ypsilanti, Mich., January 11, 2000.

¹⁵ U.S. Army, “Draft Mission Needs Statement for Future Combat Vehicle (FCV) Capability,” January 23, 2000, pp. 6–7.

¹⁶ The Army eventually eliminated the 96-hour deployment objective, but not until January 2005, at which point the change was largely irrelevant since it had already shaped so many other requirements that remained central. Shinseki AUSA speech, October 12, 1999.

The Army Vision was, in effect, the prime mover for the FCS program. In addition to placing the weight of the Chief of Staff firmly behind the project, it set down the main priorities and core assumptions that would guide the development of FCS concepts and requirements over the next several years: that revolutionary deployability would be the future Army's defining characteristic; that such deployability would necessitate C-130 transportability and radically reduced logistics demands; that it would dominate warfare across the spectrum of conflict, from major theater wars to stability and support operations; that a common network and long-range, early-attack lethality would enable survivability; and that critical to this transformation would be state-of-the-art, though as yet unknown, technological solutions. Widely recognized as a bid to recapture the Army's perceived declining relevance during the post-Cold War era, Shinseki's vision was revolutionary by design.

The C-130 deployability requirement's prominence was reinforced in the next most important requirements document following Shinseki's October 1999 announcement of the Army Vision, the first draft of the Mission Needs Statement (MNS), in January 2000. The MNS, according to DoD-wide acquisition guidelines at the time, was supposed to "[define] in broad operational terms" the "projected mission needs of the warfighter."¹⁷ But even this early draft seemed to go beyond its mandate. Instead, it officially established a number of key performance requirements, including C-130 deployability, the capability to operate for at least one week without "maintaining, rearming, or resupply," and even hardening individual platforms against "high-altitude electromagnetic pulse [HEMP], electromagnetic environmental effects interference (E3I), high-powered microwave, lasers, initial nuclear weapons effects, and NBC contamination."¹⁸ These were explicit performance requirements that, judging from DoD-wide instructions at the time for generating requirements, may have fit more appropriately in a Statement of Requirement Capabilities (SoRC) or Operational Requirements Document (ORD) years later.

Early Requirements Established Priorities and Measurements

Part of the reason for introducing explicit requirements so early was that, in early 2000, DARPA solicited bids from industry for a 24-month design concepts phase, during which four contractor teams would develop preliminary operational concepts

¹⁷ Chairman of the Joint Chiefs of Staff, "Requirements Generational System," CJCSI 3170.01B, Washington, D.C.: Joint Chiefs of Staff, April 15, 2001, pp. A-1, A-2.

¹⁸ U.S. Army, "Draft Mission Needs Statement for Future Combat Vehicle (FCV) Capability," 2000, p. 4. HEMP is an "electromagnetic energy field produced in the atmosphere by the power and radiation of a nuclear explosion," intended to damage "electronic equipment over very wide area, depending on the design of the nuclear device and altitude of the burst." Clay Wilson, "High Altitude Electromagnetic Pulse (HEMP) and High Power Microwave (HPM) Devices: Threat Assessments," Washington, D.C.: Congressional Research Service, CRS Report for Congress, August 20, 2004, p. 3.

and functional designs for FCS.¹⁹ The draft MNS was needed for program managers to articulate to the industry teams what exactly the government wanted.²⁰ The objectives of this early phase were experimental and conceptual: “Explore innovative technology solutions; Enable [the] Army to achieve [its] vision of lightweight, lethal, survivable, multi-mission ground combat forces; [and] Help DARPA and Army determine a course of action leading to the development of truly innovative future combat systems.”²¹

As the draft MNS explained, the Future Combat Vehicle (FCV), as the program was known at the time,

[Will] facilitate deployment in unit sets on C-130-like (volume and weight) platforms to include the Joint Transport Rotorcraft. Immediately upon arrival in the area of operations, FCV equipped forces must be capable of fighting as units and individual FCV platforms must be fully operational and capable of carrying all vehicle crews, troops, cargo and supporting equipment.²²

While more detailed performance specs were unavailable at this point, lofty targets for high-priority requirements, in addition to broad conceptual guidelines about how the force would operate, were useful for driving the teams to achieve ambitious capability objectives.

C-130 Transportability and Sub-20-Ton, Combat Ready Vehicles Were Singled Out as the Only Non-Tradable Requirements

The draft MNS defined C-130 deployability as critical to achieving both “rapid tactical and strategic air deployment.”²³ At a briefing to industry teams in January 2000, less than two weeks before the release of the Phase 1 solicitation and draft MNS, the FCV program manager singled out C-130 deployability as the only “non-tradable requirement.”²⁴ The DARPA solicitation went one step further, adding as a second non-tradable requirement that the vehicles, in combat ready configuration, would also have

¹⁹ Jeff Drezner, untitled draft monograph, Santa Monica, Calif.: RAND Corporation, 2005, p. 12; LTC Marion Van Fosson, “FCS Industry Day Brief,” unpublished briefing slides, Ypsilanti, Mich., January 11, 2000.

²⁰ Interview with former LSI official, March 7, 2011.

²¹ F.L. Fernandez, “Future Combat Systems Industry Day,” unpublished briefing slides, Ypsilanti, Mich., January 11, 2000.

²² U.S. Army, “Draft Mission Needs Statement for Future Combat Vehicle (FCV) Capability,” 2000, p. 5.

²³ U.S. Army, “Draft Mission Needs Statement for Future Combat Vehicle (FCV) Capability,” 2000, p. 5.

²⁴ Van Fosson, 2000.

to weigh less than 20 tons.²⁵ Other “system goals” at the time included a 33–50 percent decrease in logistics sustainment requirements, 50 percent decrease in fuel consumption, 96 hours rapid response, five days’ OPTEMPO operation without resupply, 100 kilometers per hour (kph) burst speeds, and 60 kph cross-country sustained speed.²⁶

These demanding targets went far beyond the thresholds laid out in the draft MNS, and the intent was clear: to stimulate the industry teams to develop state-of-the-art technologies. To get the most out of the CTD phase and encourage contractors to push the envelope, the Army wanted to set the bar high. The emphasis of the program was clear as well. While the MNS envisioned an interdependent force of manned and unmanned air and ground elements, linked together by a seamless tactical network, from the beginning, the Army was fixated on the manned ground vehicles. Doing so at such an early point in the process may have underemphasized, to the eventual detriment of the program, the equally or arguably even more important network component of the program, without which the Army’s vision of a lightweight yet powerful combat force would be unreachable. The Army, while it had good reason to covet a revolutionary family of vehicles, may have inadvertently jumped the gun. By frontloading ambitious requirements on the vehicle, it made the vehicle the core engineering challenge from the outset. In hindsight, the network, which was the sine qua non for the system of systems and would have underpinned the vehicles’ revolutionary capabilities, was the first and more basic technical hurdle.

The C-130 Requirement Became Difficult to Remove Without Fundamental Revisions

While pivotal in driving the technical design of FCS, the C-130 transportability requirement was also central in underpinning core aspects of the FCS operational concept. Removing it would have introduced major inconsistencies into the overarching plan, which made that requirement difficult to revise without overturning fundamental notions about how FCS would fight. The result was an added source of inflexibility in both concepts and requirements, which had a significant impact on FCS throughout the life of the program.

C-130 Transportability Was Initially Considered Suboptimal

By early 2000, C-130 transportability had already become a crucible. Yet the C-130 was originally conceived of as a convenient surrogate or “placeholder” for futuristic, heavy-lift helicopters during the AAN wargames in the late 1990s.²⁷ At the time, the Army was developing concepts for “Future Transport Rotorcraft” or “Joint Transport

²⁵ Defense Advanced Research Projects Agency (DARPA), “Future Combat Systems Solicitation (FINAL),” Contract Solicitation, January 31 2000.

²⁶ Van Fosson, 2000.

²⁷ Interview with former U.S. Army official, January 18, 2011.

Rotorcraft,” and planners assumed that such aircraft would have at least the same payload capacity as the C-130.²⁸ By the time the Army refined the FCS operational concept in November 2001, the goal was for a variety of lift platforms, including C-130 profile aircraft and “advanced vertical and horizontal lift aircraft,” to enable inter- and intratheater operational maneuver.²⁹ If strategic deployment was rapid enough, FCS forces might be able to “deter hostilities and preclude war,” in which case FCS forces would conduct stability operations (Figure 4.1).³⁰ If deterrence failed, the idea was for both types of aircraft to conduct “forcible entry” operations “from both strategic and operational distances,” creating “diverse, manifold dilemmas for adversaries” and overwhelming anti-access capabilities by “arriving at multiple points of entry.”³¹ This would include rugged airstrips not accessible to larger C-17 and C-5 aircraft.

Doing so would enable FCS forces quickly and decisively to defeat the “center of gravity of any adversary” before the adversary had the opportunity to complete its force build-up and set in place, which would strengthen its position and make offensive operations more difficult.³² C-130s, C-5s, and advanced aircraft assumed to exist in the future were envisioned as working in tandem. But within a year, the Army eliminated long-term funding for the heavy-lift rotorcraft program, and the FCS program was left to rely on the C-130 alone to realize its tactical deployment concepts.³³ Yet official deployment requirements continued to reflect optimism that advanced aircraft would eventually become available, and the ORD listed separate objective intratheater deployment capabilities for current and future aircraft.³⁴ The C-130 profile, meanwhile, was thought to give the Army maximum flexibility in pursuing advanced vertical lift as well as super short takeoff and landing concepts.³⁵

²⁸ Neil Baumgardner, “Army Struggling to Find Funding for Air Maneuver Transport,” *Defense Daily*, October 31, 2002, p. 1. The program had previously been known as “Future Transport Rotorcraft” or “Joint Transport Rotorcraft,” but the Army renamed it in 2001 in order to expand the Army’s options to include super-short takeoff and landing fixed-wing aircraft or tilt-wing aircraft rather than just rotor aircraft.

²⁹ U.S. Army Objective Force Task Force, “Objective Force White Paper: Concepts for the Objective Force,” Washington, D.C.: U.S. Army, October 2001.

³⁰ U.S. Army Objective Force Task Force, 2001, p. 6.

³¹ U.S. Army Objective Force Task Force, 2001, p. 6.

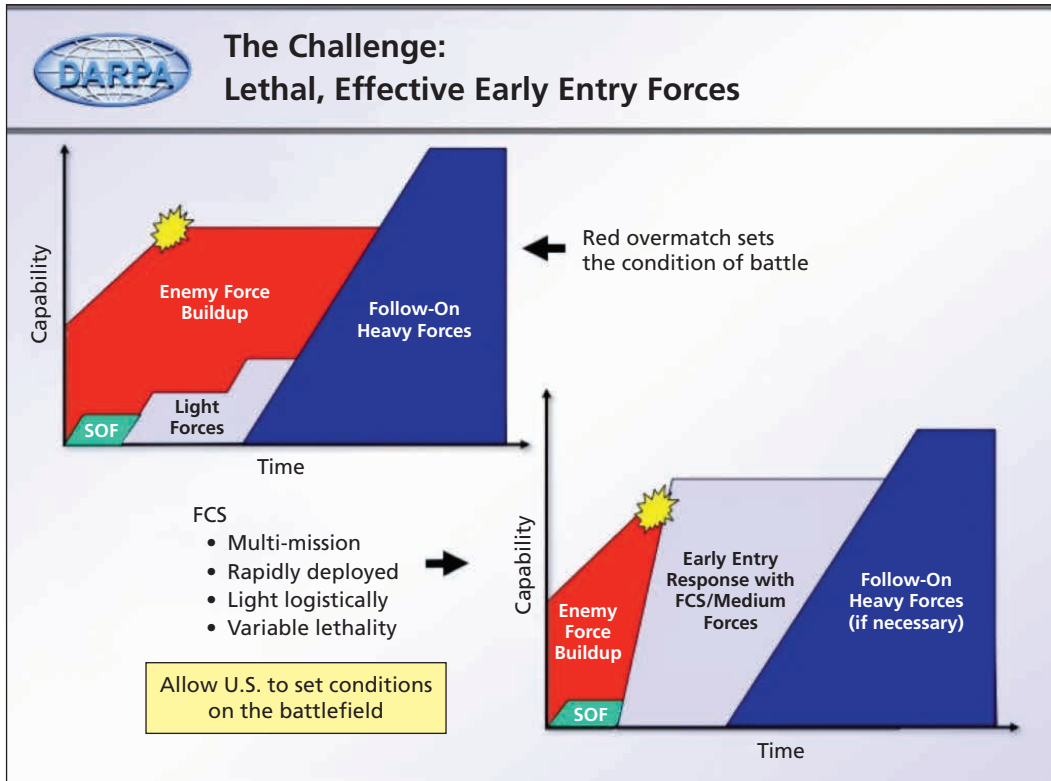
³² U.S. Army Objective Force Task Force, 2001, p. 6.

³³ The prospects for developing heavy-lift rotorcraft dimmed in October 2002, when the Army defunded the project in the FY04–09 Program Objective Memorandum long-term spending plan. Baumgardner, 2002, p. 1.

³⁴ UAMBL, “Operational Requirements Document for the Future Combat Systems: JROC Validated/Approved Change 1 (As of 23 Sep 04),” Fort Knox, Ky.: UAMBL, January 31, 2005, p. 49.

³⁵ UAMBL, “TRADOC Pamphlet 525-3-90/O&O: The United States Army Objective Force Operational and Organizational Plan for Maneuver Unit of Action,” Fort Monroe, Va.: TRADOC, July 22, 2002, p. 15.

Figure 4.1
Leveraging FCS to Improve Strategic Responsiveness



SOURCE: F.L. Fernandez (DARPA Director), "Future Combat Systems Industry Day," PowerPoint Briefing, January 2000.

RAND MG1206-4.1

C-130s Were Intended to Enable Ambitious Intertheater and Revolutionary Intratheater Deployment Concepts

While the C-130 transportability requirement was tied directly to tactical/intratheater airlift, it was also considered critical to achieving the 96-hour strategic/intertheater deployment objective. Such a high level of strategic throughput would have been impossible without the use of C-130s. In addition to increasing total payload capacity, the use of C-130s would also accelerate strategic deployment by taking advantage of austere, unpaved landing strips that larger and less rugged C-17s and C-5s could not use.³⁶ As the July 2002 O&O Plan explained, "Austere points of entry, not reliant on large runways, port facilities, and infrastructure, are more readily available in most

³⁶ UAMBL, "TRADOC Pamphlet 525-3-90/O&O," July 22, 2002, p. 15.

theaters.”³⁷ This would allow FCS forces to circumvent two critical barriers to airlift besides finite payload capacity: (1) the limited number of runways, and (2) the amount of tarmac space, particularly in developing countries, that could accommodate larger, heavy-lift jets better suited to strategic airlift.³⁸ As a 2001 RAND study pointed out, due to such restrictions, meeting the Army’s strategic deployment objectives would be impossible using only C-17s and C-5s.³⁹ Thus, in order for the operational concept to work theoretically, C-130 transportability had to be assumed. Were that not that case, other airlift assets would be unable to achieve the desired level of intertheater throughput, even in theory, and the concept itself would be inconsistent with standing, operational requirements at the time. Even using C-130s, transporting large numbers of medium-weight vehicles by air may not have been faster than using ships. Before Milestone B, the Army carried out an experiment comparing deployment of C-130-transportable vehicles by air versus by sea, from Fort Lewis, Washington, to Afghanistan, and found that deploying the vehicles by sea was significantly faster.⁴⁰

Nonetheless, in all four official versions of the O&O Plan, C-130 transportability was listed as one of six “key assumptions” of the Objective Force operational concept, along with the presumption that the acquisition community would “be able to deliver required technologies” and that “resources [would] be available.”⁴¹ TRADOC eventually eliminated the original, 96-hour deployment metric in the fourth iteration of the O&O Plan, dated December 16, 2005, suggesting that Army planners eventually accepted that the goal was unrealizable.⁴² Even so, C-130 transportability remained

³⁷ UAMBL, “TRADOC Pamphlet 525-3-90/O&O,” July 22, 2002, p. 15.

³⁸ UAMBL, “TRADOC Pamphlet 525-3-90/O&O,” July 22, 2002, p. 15; Alan J. Vick et al., *The Stryker Brigade Combat Team: Rethinking Strategic Responsiveness and Assessing Deployment Options*, Santa Monica, Calif.: RAND Corporation, 2001, p. xx.

³⁹ Vick et al., 2001; interview with former TRADOC official, April 13, 2011. FCS MGVs were also given an initial weight limit of 19 short tons, so using the Strykers as surrogates for FCS MGVs worked well. RAND excluded C-130s from the analysis because they are “not a good choice for long-range deployments, given their range, speed, and payload limitations.” However, beyond this restriction, it allocated a full one-fourth of air force heavy lift aircraft for the theoretical exercise. Vick et al., 2001, pp. 6–10, 18–20. The Congressional Budget Office (CBO) corroborated this assessment in 2009, when it bluntly reported that “[Even] the lightest modular brigades,” and much less so heavier FCS brigades, “will not be able to deploy to remote locations in 96 hours.” Congressional Budget Office, *An Analysis of the Army’s Transformation Programs and Possible Alternatives*, Washington, D.C.: CBO, June 2009, pp. 20–21.

⁴⁰ Interview with former program official, June 10, 2011.

⁴¹ Objective Force and FCS are used interchangeably. UAMBL, “Change 1 to TRADOC Pamphlet 525-3-90 O&O: The United States Army Objective Force Operational and Organizational Plan Unit of Action,” Fort Knox, Ky.: UAMBL, November 25, 2002, pp. 1–9; UAMBL, “Change 2 to TRADOC Pamphlet 525-3-90 O&O: The United States Army Objective Force Operational and Organizational Plan Maneuver Unit of Action,” Fort Knox, Ky.: UAMBL, June 30, 2003, pp. 1–6.

⁴² UAMBL, “Change 3 to TRADOC Pamphlet 525-3-90: The United States Army Objective Force Operational and Organizational Plan for the Future Combat Systems Brigade Combat Team,” December 16, 2005, p. 5.

in critical ORD requirements for intertheater as well as intratheater deployment, and continued to underpin the deployability parameter.⁴³ This made the requirement difficult to relax without fundamental revisions to the operational concept.

Ambitious, Initial Requirements Were Based on Tenuous Technical Analysis or Evidence of Achievability

In hindsight, few of these early performance requirements were realistic, and none apparently had been seriously vetted for technical feasibility, let alone affordability.⁴⁴ The 96-hour deployment metric, for instance, originated in the office of the Chief of Staff, but the conceptual or technical foundations for this figure appear to have been weak or nonexistent. While the goal to accelerate intertheater deployment of large Army forces traced back at least to Army After Next, which began in 1997, there is no evidence that the studies specifically recommended 96 hours, or any other detailed timeline, as the objective for deploying a combat-capable brigade anywhere in the world. Several former program officials recalled that the 96-hour deployability objective was not validated prior to or immediately after October 1999.⁴⁵ Despite never having been analytically validated or formally accepted as an enforceable requirement, the 96-hour deployment objective quickly became an irrefutable touchstone for the program.⁴⁶

The 20-ton weight limit for combat-ready systems was also inserted into the program based on questionable proof of technical feasibility. While 20 tons is approximately the cargo weight limit for a C-130, a 20-ton vehicle would, as it was well known, severely strain a C-130's range and would be useful only in perfect conditions for the transport. In this sense, the weight and transportability requirements seem to have been, at least to some degree, inconsistent. Requirements developers later tightened the weight requirement to 19 tons to reduce the impact on C-130 performance and to extend its range. As several interviewees indicated, most requirements were not subjected to rigorous analysis until after the Army completed a draft concept in July 2002.

⁴³ UAMBL, "Operational Requirements Document (ORD) for the Future Combat Systems," Fort Knox, Ky.: UAMBL, April 15, 2003; UAMBL, "Operational Requirements Document (ORD) for the Future Combat Systems: JROC Validated/Approved Change 1 (As of 23 Sep 04)," Fort Knox, Ky.: UAMBL, January 31, 2005; UAMBL, "Operational Requirements Document (ORD) for the Future Combat Systems: 27 Apr 06 JROC Approved/Validated Change 2," Fort Knox, Ky.: UAMBL, April 27, 2006; UAMBL, "Change 3 to TRADOC Pamphlet 525-3-90," 2005.

⁴⁴ Interview with TRADOC official, April 12, 2011; interview with TRADOC official, April 12, 2011.

⁴⁵ Interview with former program official, June 10, 2011; interview with TRADOC official, April 12, 2011; interview with TRADOC official, April 12, 2011.

⁴⁶ Interview with former program official, June 10, 2011; interview with TRADOC official, April 12, 2011.

Contractors Had Flexibility to Pursue Creative Operational and Design Concepts, but the C-130 Crucible Became an Early, Impractical Constraint

At this early stage, however, FCS was still more of a strategic vision than a meticulous plan, and the government, creatively, left the contractor teams in charge of translating the Army's high-level objectives into more detailed operational concepts, system characteristics, and technological solutions.⁴⁷ Their mission was to explore concepts and requirements for a "system of systems design starting with a 'clean sheet of paper.'"⁴⁸ Except for the two critical constraints—20 tons and C-130 transportability—the government's formal guidelines were lenient, allowing room for contractors to develop innovative proposals. Inserting two non-negotiable requirements, in other words, does not seem unreasonable, given the government's clear prioritization of deployability and the freedom that the industry teams otherwise enjoyed. The four months between Shinseki's announcement of the Army Vision and the release of the Concepts Design Phase solicitation may have allowed too little time for serious technical vetting, and even if the hard requirements were inaccurate, they would have plenty of time to adjust them later.

Although program officials may have expected serious analysis to occur later, establishing such ambitious objectives so early in the program indicates the degree to which the Army was willing to use unvetted figures to help establish far-reaching objectives. Setting the bar so high, so early, even for the most important requirement, may not have been the best approach. It pushed contractors to develop revolutionary designs that theoretically would have achieved the Army's key deployment objectives, but cementing these two requirements and tying them to such a high-level authority so early made them unnecessarily difficult to relax from the beginning. More fundamentally, it quickly elevated one priority—deployability—above all others, without sufficient understanding of what other characteristics, like survivability, the Army would have to sacrifice as a result. While enhanced deployability was a valid goal, by defining that objective so narrowly, the Army preempted important questions about the practical utility of that level of deployability and the likely impact on other, arguably equally important capabilities. Those are questions that may have warranted more deliberate consideration.

Difficult Transportability Requirements Were Partly Intended as Design Constraints

Regardless of operational or technical feasibility, ambitious transportability and weight requirements set an extraordinarily high bar that was intended to push the Army's

⁴⁷ DARPA, January 31, 2000.

⁴⁸ DARPA, January 31, 2000.

acquisition community beyond apparent technological limits. The goal was to develop truly state-of-the-art, revolutionary technologies. The approach was based at least partly on the assumption that extremely ambitious requirements would force engineers to develop innovative or breakthrough solutions, which, even if they fell short of formally established threshold targets, would presumably enable greater capabilities than if engineers were given less ambitious targets.⁴⁹

C-130 Transportability Was Thought to Play the Role of a “Forcing Function” Rather Than a Realistic Requirement

The C-130 transportability requirement, for instance, has been widely described by former program officials more as a design constraint, or “forcing function,” than a realistic requirement.⁵⁰ Lieutenant General Joe Yakovac, the FCS Program Manager from 2001–2003, for instance, explained in an August 2009 conference that C-130 transportability was a “stretch goal,” and that the MGV “was never meant to fly inside of a C-130,” at least intact rather than partially disassembled.⁵¹ While being able to deploy FCS forces via C-130s would have added significant capability, as Yakovac explained, the C-130 was a “design constraint to keep the weight down.”⁵² In 2005, likewise, Army Secretary Francis Harvey told reporters that the C-130 constraint was a “design template” intended to stimulate creative engineering.⁵³ Around the same time, CSA General Peter Schoomaker explained that as MGV weight estimates crept upward, C-130 sizing would “remain a priority despite any logistical difficulties associated with the use of the aircraft.”⁵⁴ He wrote that designing MGVs within the C-130 envelope would “provide a wider range of crossable bridges; improve tactical mobility; enable the reduction of the logistics footprint; and facilitate greater strategic deployability with up to three MGVs being transported on a C-17.”⁵⁵ Although lofty operational concepts were indeed important, Army officials, apparently well aware by at least 2005 of the impracticality of C-130 deployment, also realized its value as a forcing function.⁵⁶

⁴⁹ Interview with former program official, June 10, 2011.

⁵⁰ Email correspondence with Army official, August 10, 2011.

⁵¹ Lieutenant General Joseph Yakovac, “The Future of the U.S. Army: Options for Force Modernization,” speech delivered at The Center for National Policy, Washington D.C., August 27, 2009.

⁵² Yakovac, “The Future of the U.S. Army,” 2009.

⁵³ Greg Gant, “Rolling FCS into Reality: Prized Program Requirements Shift with Development,” *Army Times*, October 3, 2005.

⁵⁴ “Schoomaker Tells FCS Office to Pursue 24-ton Manned Ground Vehicles,” *Inside the Army*, June 6, 2005.

⁵⁵ “Schoomaker Tells FCS Office to Pursue 24-ton Manned Ground Vehicles,” 2005.

⁵⁶ In testimony to the House Armed Services Committee in 2005, Claude Bolton remarked:

[We] have decided that we want to use the box size of the 130 to size the future combat system. Why? Well, if we can do that, we drive down the logistics tail. If you have to use a C-130 into theater for any reason, the commander has that flexibility. Not saying that's going to be the Con-Ops, because currently it's not. Now can we

Likewise, in January 2000, the Deputy Assistant Secretary for Research and Technology described C-130 transportability as “an excellent way to keep the FCV size and weight manageable.”⁵⁷ Short of an advanced, new transport aircraft, the C-130 envelope would act, at least in part, as a “forcing function” on engineers to drive them to control vehicle size, weight, and logistical requirements aggressively.⁵⁸ Senior leaders allegedly realized this at the time and admitted that ultimately C-130 requirement or some other, important capability would eventually have to be relaxed.⁵⁹

Using difficult transportability requirements as a forcing function for weight control was never formalized as part of the FCS acquisition strategy. It was not primarily responsible for the development and persistence of the C-130 requirement, but the attitude played a significant role. The Army’s desire to be able to deploy FCS brigades via C-130s was based on valid strategic needs, and parts of the user community insisted years into the program that they needed the C-130 requirement in order to achieve intratheater deployment.⁶⁰ Yet evidence from interviews and public statements suggests that the fact that C-130 transportability forced engineers to work toward revolutionary advances in weight reduction, logistics, and protection extended its perceived utility beyond the stated capacity to deploy FCS forces, a capability that engineers quickly found to be infeasible. The approach also seemed to conflate requirements and what one former engineer on the FCS program described as “desirements,” which can usefully motivate advanced technology invention and exploration if they cannot be achieved practicably or produced industrially.⁶¹ One lesson from FCS might be the need to discriminate between these two notions, requirements and desirements, more discerningly.⁶²

do that today? No. We don’t have the technology today to do that. We’re trying to mature that over the next 18 months to see if we can get there. How close will we get? I can’t answer that today.

Claude Bolton, “Fiscal Year 2006 Budget Request for Future Combat Systems, Modularity and Force Protection Initiatives,” Hearing of the Tactical Air and Land Forces Subcommittee of the House Armed Services Committee, Washington, D.C., March 16, 2005.

⁵⁷ Andrews, “Future Combat Systems (FCS) Industry Day,” January 11, 2000.

⁵⁸ An attitude that engineers simply had to “try harder” was reportedly prevalent across the FCS program among requirements developers and high-level officials. Meanwhile, a similar sense of exasperation seemed to color many engineers’ attitudes toward the requirements community. Regardless of the direct impact of these sentiments on the requirements process, it is indicative of an important deficit of trust and synergy between the requirements and engineering communities.

⁵⁹ Email correspondence with Army official, August 10, 2011.

⁶⁰ Interview with TRADOC official, April 12, 2011.

⁶¹ Richard A. Lawhern, “Out-Brief on Lessons Learned from the Future Combat Systems Program,” unpublished white paper, July 29, 2009.

⁶² Lawhern, “Out-Brief on Lessons Learned from the Future Combat Systems Program,” 2009.

Brigade Designs Were Driven by Broad Concepts and Performance Criteria

While a small number of high-priority and high-impact requirements primarily affecting manned vehicles became fixed quickly, a relatively flexible framework defined at the brigade level allowed for innovation among the contractor teams competing to develop the FCS operational and design concept. Between October 1999, when Shinseki unveiled FCS as the Army's transformation objective, and January 2000, when DARPA and the Army released the solicitation for Phase 1, the operational concept evolved slightly, but not significantly, from Shinseki's original vision. While the Army nailed down key transportability requirements and set other ambitious performance targets, from an operational standpoint, its vision remained relatively imprecise and high-level: the force would consist of sub-20-ton vehicles and unmanned air and ground assets linked together by a seamless network of information that would enable information dominance and preemptive, decisive engagement with the adversary. It would be capable of direct and indirect fire, air defense, reconnaissance, troop transport, and would have nonlethal, mobility/countermobility and command and control capabilities.⁶³

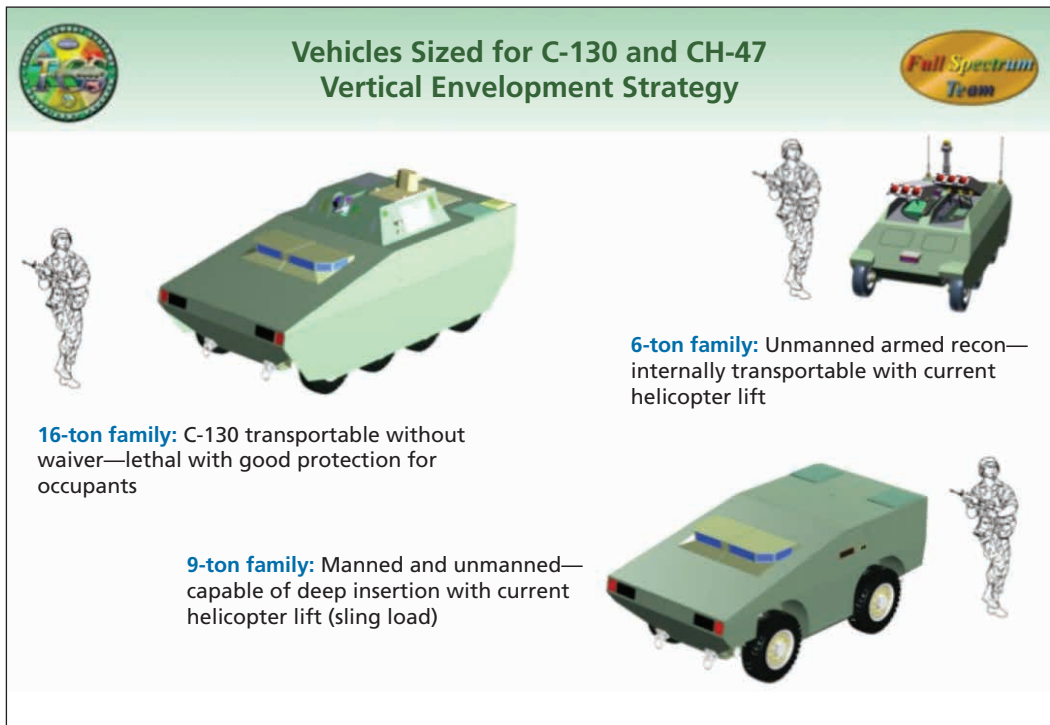
In January 2000, the Army handed down this broad framework to the four industry teams (recall Table 3.2) to fill out the concept, elaborate upon the design and performance requirements, and identify and assess needed technologies. For the next year and a half, the contractor teams developed detailed operational schemes, generated engineering models of key systems, and evaluated their concepts and designs at government labs using modeling and simulation programs, including JANUS, CAST-FOREM, and MAPEX at the TRADOC Analysis Center at White Sands Missile Range (TRAC-WSMR) and elsewhere. In March and again in June 2001, TRADOC fed the four teams draft versions of the O&O Concept, and over the next several months visited each team for progress updates.⁶⁴ In late September 2001, for example, Team Full Spectrum, which SAIC led but also included Honeywell, United Defense, Northrop Grumman, Georgia Institute of Technology, SRI International, and several others, delivered almost two full days' worth of briefings to Army representatives. Their update included a proposed brigade organization, a concept of operations (CONOPS) that envisioned the brigade deploying rapidly and fighting immediately upon arrival, a sensor concept, C4ISR architecture, and even a preliminary risk mitigation approach.⁶⁵ Team Full Spectrum's initial design concept (Figure 4.2) was significantly different from what TRADOC eventually settled upon. Most strikingly, the

⁶³ DARPA, January 31, 2000.

⁶⁴ James N. Walbert, "Future Combat Systems Analysis Team Feedback to Industry," unpublished briefing slides for Full Spectrum Team, October 29, 2001.

⁶⁵ John Gully, "Briefing to A-Team," unpublished briefing slides to U.S. Army, September 20, 2001.

Figure 4.2
Team Full Spectrum Vehicle Design Concept



SOURCE: John Gully, "Briefing to A-Team," unpublished briefing slides to U.S. Army, September 20, 2001.
 RAND MG1206-4.2

team proposed three separate families of ground vehicles: 16-ton manned vehicles that would be C-130 transportable; 9-ton manned and unmanned vehicles that would be CH-47 transportable; and 6-ton unmanned armed recon vehicles that would be helicopter transportable.⁶⁶ The other three teams' operational and design concepts were, within the limits that the Army imposed, diverse as well.

From September through October 2001, the Army evaluated the draft proposals from the four contractor teams, and in early November delivered feedback in addition to a refined MNS and a SoRC, effectively a summary draft of emerging, high-priority operational requirements. While the MNS encapsulated the maturing operational concepts articulated in draft versions of the O&O Plan, such as the seminal notion of "see first, understand first, act first, and finish decisively," the SoRC spelled out 92 required performance capabilities. The capabilities required were generally broad, but did include some relatively specific parameters, such as the capability to conduct route

⁶⁶ Gully, "Briefing to A-Team," 2001.

reconnaissance at speeds of at least 50 kph, in addition to the already well-established transportability requirements.⁶⁷ The teams were responsible for integrating the feedback and refined capability requirements (from the SoRC) and operational concepts (from the O&O Plan) into their proposals.

In 2001, the Army Compressed by Half the Amount of Time for Generating Concepts and Operational Requirements for Milestone B Review

Originally, when the program kicked off in early 2000, DARPA and the Army had planned to down-select the four contractor teams to three in July 2002, again to two in April 2003, and then carry both remaining designs into a detailed design and final build for a 2006 Milestone B.⁶⁸ In September 2001, at a meeting less than a week before September 11, however, the Army decided to accelerate Milestone B by three years, pushing the deadline for down-selecting to two industry concepts to February 2002. Over the next two months, the Boeing and SAIC teams merged and submitted a joint proposal to DARPA in mid-January 2002 with a revised concept merging the Boeing and SAIC Phase 1 designs.⁶⁹ The team adjusted their concept as well, cutting out the family of 9-ton manned vehicles due to their insufficient survivability capabilities, and fleshing out the MGCV family with nine 16–18 ton vehicles, including BLOS/LOS, mortar, NLOS, C2, reconnaissance and surveillance, and resupply vehicles, in addition to carriers for infantry and for tube-launched, small UAVs. Also conceived as part of the system of systems were four unmanned ground vehicles and three UAVs.⁷⁰ The other two contractor teams, Team Gladiator, led by TRW and Lockheed Martin, and Team FoCUS Vision, headed by General Dynamics Land Systems and Raytheon, also bid on the CTD Phase 2 contract.⁷¹ In early March 2002, DARPA selected the Boeing/SAIC team as the LSI, giving it just over a year to prepare for Milestone B, scheduled for the following April.⁷² At this point, TRADOC ramped up its efforts to generate and define concepts and requirements for FCS, drawing on a number of government and industry sources, including the final proposal submitted by the Boeing/SAIC team.

⁶⁷ UAMBL, "Statement of Required Capabilities: Future Combat System of Systems (FCS)," Fort Monroe, Virginia: TRADOC, November 2, 2001. Three subsequent versions of the FCS Statement of Required Capabilities (SoRC) were published as part of successive versions of the O&O Plan in July 2002, November 2002, and June 2003.

⁶⁸ U.S. Army Objective Force Task Force, "Objective Force Task Force . . . Beyond Relevancy and Readiness: After Action Report," unpublished report, Washington, D.C.: U.S. Army, April 28, 2004.

⁶⁹ Boeing, "Proposal to DARPA/Army for the Future Combat Systems, Volume 1: SoRC Compliance over Time," unpublished proposal, January 17, 2002, p. 87.

⁷⁰ Boeing, "Proposal to DARPA/Army for the Future Combat Systems, Volume 1: SoRC Compliance over Time," 2002, pp. 90–94.

⁷¹ Neil Baumgardner, "Three Teams Forming to Compete for LSI Effort," *Defense Daily*, January 9, 2002.

⁷² "Boeing-SAIC Team Picked as FCS Lead System Integrator," *Defense Daily*, March 8, 2002.

TRADOC Made Important Progress by Standing Up an Integrated Requirements Organization and Designing Brigade-Level CONOPS

In January 2002, as DARPA was preparing to select the LSI and transfer full management responsibilities to the Army, TRADOC, which had drafted the O&O Concept and MNS, stepped into a more active role generating and managing requirements. One of its most important steps was to establish the Unit of Action Maneuver Battle Lab (UAMBL) to pull together and integrate user requirements from across the Army and to carry out experiments and evaluations to validate the requirements.⁷³ The Army decided to locate UAMBL at Fort Knox, which housed the U.S. Army Armor Center and School, because the base already had substantial capabilities to conduct modeling and simulation and to connect with key training facilities at other Army installations.⁷⁴ As it was being stood up, UAMBL recruited combat developers from 12 different centers and schools across the Army with a stake in FCS, from the Aviation Center at Fort Rucker, Alabama, to the Chemical and Engineer Schools at Fort Leonard Wood, Missouri.⁷⁵ The objective was to bring together subject matter experts and relevant stakeholders and place them in a single organization in order to prevent individual schools from developing requirements in isolation from other parts of the Army.⁷⁶ While all of the UAMBL recruits were experienced Army officers and civilians, some were given high-level responsibilities with little to no background in combat development.⁷⁷ Moreover, none had ever developed so large and complex a set of requirements as they were attempting with FCS.

The requirements generation process for most acquisition programs is typically stove-piped, with little interaction among schools. Early on, TRADOC identified the Army's decentralized approach as a major obstacle to effective development of a brigade-level set of integrated requirements. In this sense, UAMBL itself, as an organization, represented important progress within the requirements community, because it brought together the typically stove-piped stakeholders that develop requirements for acquisition programs. Only an integrated organization such as UAMBL would be able to design an entire brigade of interlocking systems from the ground up, rather than adding new systems piecemeal to existing brigades of legacy platforms. The beauty of such an approach was that it would allow the Army to design the constituent systems to ensure interoperability from the beginning, which would enhance overall brigade performance. This was the logic behind the SoS framework and one of the major assumptions that underpinned the FCS operational concept: that advanced networked communications would

⁷³ Interview with TRADOC official, April 12, 2011.

⁷⁴ Roxana Tiron, "At Unit of Action Lab, Soldiers Determine Design of FCS," *National Defense*, November 2003.

⁷⁵ Interview with TRADOC official, April 12, 2011; Tiron, 2003.

⁷⁶ Interview with TRADOC official, April 12, 2011.

⁷⁷ Interview with TRADOC official, April 12, 2011.

enable FCS to substitute tactical omniscience for heavy armor, thereby achieving both lightweight deployability and undiminished lethality and survivability. From a requirements perspective, UAMBL was to be the enabler for this novel approach.

The Operational and Organizational Plan Represented the Best Example of an Integrated, Brigade-Level Approach to Force Design

UAMBL's most valuable output was the O&O Plan, initially a 175-page document that eventually stretched to over 400 pages. Prior to Milestone B, this was arguably the most important source of requirements, since it provided a conceptual foundation for the development of the ORD. The origin was the O&O Concept, which TRADOC (pre-UAMBL) used to capture high-level guidance from senior Army leaders as well as operational themes from Army After Next, from which many ideas and concepts migrated directly into the FCS.⁷⁸ TRADOC fed at least two versions of the O&O Concept, compressed papers no longer than 20 pages, to the contractor teams during CTD Phase 1. The contractor teams, in turn, drawing on technical experts, helped UAMBL develop the O&O Plan by elaborating on embryonic concepts of networking to describe in greater technological detail, for instance, what types of sensors could be integrated and how they would operate.⁷⁹ Despite the diversity of sources, UAMBL was primarily responsible for authoring the O&O Plan, and it effectively integrated diverse concepts and ideas coherently.

By the time UAMBL released its first draft in July 2002, the O&O Plan described how an FCS-equipped brigade would be organized, how it would fight, how it would integrate required operational capabilities, and how it would operate in different types of combat, as modeled loosely in a series of high-level scenarios. Usefully, it also articulated the key assumptions on which the O&O development was based, including the critical presumption that the acquisition community would be able to deliver all the required technologies. The core value of the O&O Plan was that it was written from a brigade perspective. Although it outlined the roles of individual systems, the O&O Plan focused on how the FCS-equipped brigade, referred to as the Unit of Action (UA), would operate as a fully integrated combined arms unit and how the diverse systems would interoperate on the battlefield.⁸⁰ Since FCS was fundamentally about a new organization rather than, as high-priority requirements may have suggested, a high-tech family of manned vehicles, the O&O Plan played a critical role by describing FCS as an organizational framework into which all other systems and subsystems would be integrated. In this sense, the O&O Plan was—or should have been, at least in theory—the fundamental driver of the requirements for the overall FCS program.

⁷⁸ Interview with TRADOC official, April 12, 2011; interview with TRADOC official, April 12, 2011.

⁷⁹ Interview with TRADOC official, April 12, 2011.

⁸⁰ UAMBL, "Change 1 to TRADOC Pamphlet 525-3-90 O&O," November 25, 2002.

UAMBL Was Unable to Translate Integrated Concepts into Effective Integration of Operational Requirements

While UAMBL developed the O&O Plan in a relatively centralized and straightforward manner, the development of the ORD was a different story. UAMBL developed the ORD synergistically and in parallel with the O&O Plan, primarily between March and December 2002. During this time, the Army's schools and centers were, according to former UAMBL officials, intimately involved in the development of both. The 12 proponents involved in FCS fed both concepts and requirements to UAMBL, which it collected, sorted through, and wrote into the O&O Plan and ORD. The Intelligence Center at Fort Huachuca, for instance, wrote the intelligence-related requirements, while the Armor School at Fort Benning wrote the ones related to armor.⁸¹ The operational concepts were relatively high-level, giving UAMBL significant leeway to integrate them into a coherent, brigade-level set. The ORD requirements, on the other hand, were much narrower and often came with specific parameters; for instance, the MGCV would have to provide a certain percentage of crew survival against a particular size of mine, or that the UAV Class II would have to hover and stare in winds up to 20 knots.⁸²

Operational Requirements Were Not Structured to Prioritize SoS- Rather Than System-Level Functionalities

Since the core expertise on these requirements resided in the schools, UAMBL, despite its role as the centralized integrator, typically funneled requirements directly into the ORD rather than weeding out narrow parameters. There was, as a result, little sense of prioritization of requirements. Threshold requirements for systems and subsystems technically carried equal weight and became almost as difficult to modify as arguably much more important threshold requirements at the SoS level. Another issue was that, as a result of the acceleration of the CTD phase in September 2001, UAMBL had to develop the Army's largest and most complex set of requirements in an entirely new organizational framework and in a remarkably short amount of time. This limited the time that UAMBL could use to verify whether those requirements could work together or individually, and to develop a more hierarchical design concept to define in greater detail the priorities and interdependencies among requirements.⁸³ As a result, while the operational concept took a holistic approach from the brigade perspective, the design was stove-piped.⁸⁴

⁸¹ Interview with TRADOC official, April 12, 2011.

⁸² UAMBL, "Operational Requirements Document for the Future Combat Systems," April 15, 2003.

⁸³ Interview with former program official, March 7, 2011.

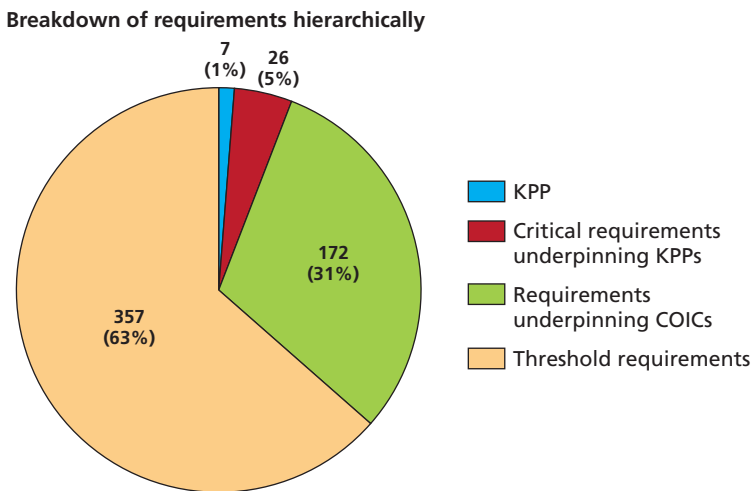
⁸⁴ Interview with former program official, February 11, 2011.

FCS Trade Space Was Overly Constrained by Too Many System-Specific Requirements

At least partly due to the fact that UAMBL was unable to integrate a brigade-level set of requirements as effectively as it was able to develop the brigade-level body of operational concepts, the ORD, as it was finalized and approved by the Joint Requirements and Oversight Committee (JROC) in mid-April 2003, was excessively detailed and dominated by threshold requirements at the system level. Although the ORD contained a number of key operational requirements at the brigade level, including seven key performance parameters (KPPs) and 26 critical requirements that underpinned KPPs, known as Critical Operational Issues and Criteria (COICs), there were several times as many threshold requirements at the level of individual systems. As a result, requirements at the system level rather than the system-of-systems level dominated the ORD, focusing design efforts at the system level and constraining critical trade space at the SoS level (Figure 4.3).

The trade space is the “set of program and system parameters, attributes, and characteristics required to satisfy performance standards.”⁸⁵ When parameters are defined narrowly, trade space narrows as well; when system parameters are defined narrowly, trade space at the system-of-systems level is virtually eliminated, because narrow system parameters can restrict engineers from offloading required capabilities

Figure 4.3
Concept Based Requirements System



SOURCE: FCS ORD Gaps Analysis, August 2005.

RAND MG1206-4.3

⁸⁵ Mark W. Brantley, Willie J. McFadden, and Mark J. Davis, “Expanding the Trade Space: An Analysis of Requirements Tradeoffs Affecting System Design,” *Acquisition Review Quarterly*, Winter 2002, p. 2.

to other systems. Being able to do so was a major advantage of the SoS approach, since capabilities desired at the brigade level could be jointly achieved by the entire set of systems that would be impossible by any one independent system.

Allowing proponent commands to define such a large number of capabilities at the system level drew away from the SoS approach and restricted important trade space intended to enable brigade-level functionalities. The Manned Combat System, for instance, had to operate silently on batteries for eight hours; survive ground and high-altitude electromagnetic pulses (EMP and HEMP), and the initial blast, thermal, and radiation effects of nuclear weapons; allow a crew to survive chemical, biological, radiological, and nuclear (CBRN) attacks for six hours without masks or protective garments; monitor personnel for contamination prior to entry; operate in -25 to $+125$ degrees Fahrenheit without special equipment or degraded performance; incorporate an embedded water generation and purification system for at least 4.1 gallons per day per soldier; provide communications to dismounted infantry 5 kilometers away; and provide a power source to charge each infantryman's electronics equipment.⁸⁶ Enabling all these requirements together, along with others, in an armored vehicle transportable by C-130 was, as engineers quickly discovered, an impossible task. Moreover, it was unclear what utility these particular, system-specific capabilities provided to the overall brigade function.

Ingrained Approaches to Developing Requirements and a Lack of Faith in the SoS-Based Survivability Concept Contributed to Bottom-Heavy ORD

Overspecified requirements at the system level were rooted in at least two other factors in addition to the continued, strong influence of the Army's proponent commands over UAMBL. The first issue is cultural. As former officials explained, the Army's requirements community tends to write overly specific operational requirements, because (a) that is how requirements traditionally have been written, and, partly as a result, (b) relatively specific requirements are easier to write and to analyze than more abstract ones that involve more than one system.⁸⁷ While the tendency within the Army is to specify narrow parameters early, this standard approach clashed with the developmental and, to a large degree, experimental nature of the FCS program. Without having developed a fundamentally new approach to requirements development, however, this conflict may have been difficult to avoid once Army leadership accelerated Milestone B by three years. Milestone B marks the transition from developing concepts and technology to generating concrete engineering solutions and beginning to manufacture full, physical prototypes. When the Army shortened the CTD phase from 2006 to 2003 and effectively displaced DARPA as the FCS lead in 2001, it quickly transformed the program from a relatively flexible technology experiment to

⁸⁶ UAMBL, "Operational Requirements Document for the Future Combat Systems," April 15, 2003.

⁸⁷ Email correspondence with Army official, August 10, 2011.

a fast-paced, regimented, and large-scale acquisition program where, as with most acquisition programs, requirements would be defined quickly and in detail.

The second issue was technological. Because the network was both (a) critical to achieving the SoS-based survivability concept and (b) one of the most technologically challenging and high-risk aspects of the program, combat developers did not entirely trust the network to compensate for heavy armor on the vehicles, one of the foundational notions underlying the operational concept. As Army and industry teams modeled the information-for-armor tradeoff during Phase 1, they discovered that the network would always fail in at least some situations. This meant that soldiers would ultimately have to rely on traditional force protection, such as heavy armor, to protect themselves from the wide array of threats, ranging from 30mm cannons to anti-tank mine blasts, against which FCS was required to be survivable.⁸⁸

Information dominance was considered to be extremely effective offensively, at least in theory, since it would allow an FCS-equipped brigade to detect and destroy adversaries preemptively and from a distance. But defensively, in situations where the enemy detected the FCS brigade first, the outer layers of the onion-like shield of information surrounding the brigade would inevitably fail, leaving soldiers to rely on traditional force protection. This lasting skepticism of the network's capabilities encouraged combat developers to compensate MGVs with levels of armor protection that inevitably pushed the vehicle's weight well over 19 tons.⁸⁹

The ORD Was Ultimately Structured More for a Family of Systems Than an Integrated System-of-Systems

While FCS managers recognized some of these issues early in the program, it was not until after the JROC had approved the first version of the ORD. In a July 2003 briefing, for instance, FCS program managers explained that continued tension between extensive capability requirements for FCS manned vehicles and their strict C-130 weight constraint stemmed from the fact that a Family of Systems ORD structure was used in lieu of SoS allocations.⁹⁰ The difference between a FoS and a SoS is that the former is a "set or arrangement of independent systems that can be arranged or interconnected in various ways to provide different capabilities," whereas a SoS is a "set or arrangement of systems that results from independent systems integrated into a larger system that delivers unique capabilities."⁹¹ A FoS, in other words, consists of systems arranged to provide unique capabilities independently; in a SoS, on the other hand, the inte-

⁸⁸ Interview with former program official, August 22, 2011.

⁸⁹ Interview with former program official, August 22, 2011.

⁹⁰ FCS Manned Ground Vehicle IPT, "Manned Ground Vehicle (MGV) Requirements Trade Process: Overview in Response to MGV Weight Challenge," unpublished briefing slides, Fort Knox, Ky., July 30, 2003.

⁹¹ Defense Acquisition University, "Family of Systems," Acquisition Community Connection website. Defense Acquisition University, "System of Systems (SoS) Engineering," *Defense Acquisition Guidebook* (online).

grated whole provides unique capabilities independent of the constituent systems. The distinction is subtle but significant, since FCS was intended to operate as a SoS rather than simply a FoS. As the July 2003 briefing indicated, however, that is not how the ORD was written. As a result, the ORD promoted “FoS element-centric views” rather than a system-level, integrated approach, and this imposed “unnecessary design burdens to MGV variants.”⁹² Overall, there was little sense of requirements prioritization or subordination in the ORD.⁹³ In an attempt to fix that, UAMBL wrote a banding document intended to show requirements dependencies and levels of priority.⁹⁴ This was a spreadsheet that color-coded requirements according to four levels of prioritization: KPP, COIC, requirements underpinning COICs, and threshold requirements. Higher-level requirements necessitated higher-level authority to adjust than lower-level requirements, and the bands were useful for visualizing how the requirements related to one another.⁹⁵ But because interconnections between them were so tight, the bands were, as one engineer explained, moot, since few requirements could be modified without necessitating changes at other levels.⁹⁶

In some cases, engineering implementation solutions were written into the ORD in the form of complementary systems intended to enable various FCS functionalities. Some were more important than others. Network requirements, however, best exemplify this approach, since the Army mandated that the Warfighter Information Network–Tactical (WIN-T) and the Joint Tactical Radio System (JTRS) be used as the “integrating information network standard for information transport, network management, information integrity, Information Dissemination Management (IDM), information assurance, and Quality of Service (QoS).”⁹⁷ Because this was a threshold requirement, UAMBL effectively defined the engineering solution that the LSI would be required to pursue, wedding the program to relatively underdeveloped technologies outside of FCS program management to achieve its critical, information-based backbone, while closing off potential alternative solutions that the LSI could have otherwise pursued.⁹⁸

⁹² FCS Manned Ground Vehicle IPT, July 30, 2003.

⁹³ Interview with former program official, March 7, 2011.

⁹⁴ Interview with former program official, March 7, 2011.

⁹⁵ Interview with former program official, August 10, 2011.

⁹⁶ Interview with former program official, August 10, 2011.

⁹⁷ UAMBL, “Operational Requirements Document for the Future Combat Systems,” April 15, 2003. As the rationale for ORD 3450 stated:

The UA and FCS must be interoperable with current Army systems, Joint and Interagency systems and adaptable to Allies, Coalitions, National networks and NGO systems. To facilitate this level of interoperability, it is imperative that all network standards be based on WIN-T standards and protocols, which are GIG CRD compliant (reference Appx D-7 GIG CRD Crosswalk).

⁹⁸ Interview with former program official, August 16, 2011.

Detailed Operational Concepts and Requirements Preceded Standard Assessments

At the time that TRADOC was developing initial requirements for FCS, it followed a system that was based loosely, but not exactly, on the process recommended by the Office of the Chairman of the Joint Chiefs of Staff (CJCS). Under the JCS system, a Mission Area Analysis (MAA) and Mission Needs Analysis (MNA) were needed first to “evaluate and justify” the development of new requirements.⁹⁹ This phase would begin with a review of strategic level guidance, such as the National Military Strategy or the Defense Planning Guidance, as well as projected threats and intelligence assessments.¹⁰⁰ If the MAA and MNA cycle identified a valid need for new requirements, an MNS would be written as a “non-system-specific statement of operational capability need written in broad operational terms,” which, after JROC approval, would lead to an ORD to define measurable operational performance requirements that the Army would then have to achieve.¹⁰¹

Under the TRADOC system, MAA and MNA studies fed into a MNS, but were preceded by several draft versions of the MNS, the O&O Concept, the O&O Plan, and the SoRC.¹⁰² The O&O Plan, in particular, strongly influenced the MAA and related documents, because it spelled out detailed operational and even performance requirements for the FCS systems. It also included an informal but important subdocument, the SoRC, which detailed a number of operational requirements and performance thresholds that flowed down from the O&O Plan.

Critical, Operational Gaps Were Presupposed and Defined as Inherent Differences Between Legacy and Future Forces

When TRADOC published the MAA on April 5, 2002, it had already been circulating draft versions of the MNS, which was supposed to come after the MAA under the JCS and TRADOC guidelines, for more than two and a half years. Moreover, TRADOC had written a detailed SoRC and a draft O&O Concept by early November 2001.¹⁰³ But the main issue was not procedural. The main issue was that the deficiencies the

⁹⁹ Chairman of the Joint Chiefs of Staff, “Requirements Generation System,” CJCSI 3170.01B, Washington, D.C.: JCS, April 15, 2001, p. C-1.

¹⁰⁰ Chairman of the Joint Chiefs of Staff, 2001, p. C-1.

¹⁰¹ Chairman of the Joint Chiefs of Staff, 2001, p. C-1.

¹⁰² TRADOC, “Force Development: Requirements Determination,” TRADOC Pamphlet 71-9, November 16, 2001.

¹⁰³ UAMBL, “Statement of Required Capabilities: Future Combat System of Systems,” November 2, 2001; TRADOC, “The United States Army Objective Force: Tactical Operational and Organizational Concept for Maneuver Units of Action,” TRADOC Pamphlet 525-3-91 (v2), November 6, 2001. A more developed O&O concept followed a month later: UAMBL, “TRADOC Pamphlet 525-3-0: The United States Army Objective Force Operational and Organizational Concept,” Draft, Fort Monroe, Va.: TRADOC, December 18, 2001,

MAA and MNA identified were deficiencies of the legacy and interim forces relative to projected Objective Force mission capabilities, and not flaws in the FCS operational concepts or emerging materiel requirements themselves. The operational need for FCS was defined by the gap between the legacy and objective capabilities, and since the FCS program's ambitions were far beyond any current capabilities, this need was inherent from the beginning. Shinseki justified that need as early as October 1999 in the Army Vision, and a draft MNS published several months later articulated that overarching requirement for FCS:

The Army's current forces are not designed or equipped to respond adequately to crises short of war. Heavy units are not quickly deployable, and are difficult and costly to sustain; light units lack staying power, lethality and tactical mobility. The operational capabilities envisioned to meet this requirement are not provided in any existing organizational design or emerging ground combat system.¹⁰⁴

The MNA, on the other hand, generalized the deficiencies of legacy and interim forces, which the MAA had highlighted using the same logic, into seven areas (deployment, sustainment, etc.), and then developed broad solutions/implications for each of these deficiency areas, with strongest consideration given to Objective Force concepts.

Of course, these concepts had already been well developed in draft versions of the MNS and SoRC by May 2002 and created inherently large capability gaps relative to the legacy and interim forces. The analysis was therefore redundant and confirmatory. The mission needs identification process, and the MAA and MNA stages of that process in particular, were thus exercises in syllogistic reasoning: the futuristic Objective Force concepts created an inherent capability gap with older forces, since they were designed to execute operational concepts of which legacy and interim forces were incapable. The MAA and MNA identified obvious and inherent differences between future and older forces, and then justified the need for FCS based on those deficiencies. The question that the process ignored was whether those operational concepts were really needed or possible to begin with.

cited in Krepinevich and Montgomery, July 2009, p. 7. A Boeing document from September 2002 entitled "Future Combat System (FCS) Supportability Strategy: Volume 1 of 13," explained that

The FCS program was created based on a Mission Need Statement and a Statement of Requirements Capabilities that the FCS systems must meet. These requirements provide the minimum acceptable set of requirements to satisfy the needs of the U.S. Army for a rapidly deployable, lethal, survivable, and sustainable force.

Boeing Company, "Future Combat Systems Supportability Strategy: Volume 1 of 13," Document No. D786-10025-1, September 27, 2002, pp. 20–21.

¹⁰⁴U.S. Army, "Draft Mission Needs Statement for Future Combat Vehicle (FCV) Capability," January 23, 2000, p. 6.

TRADOC Recognized the Importance of Asymmetric Warfare Early

One upshot of the failure to assess the FCS operational concept rigorously before Milestone B was that the compatibility of FCS concepts with alternative mission scenarios was not well validated. Since program inception, FCS has faced criticism that it was “not optimized for the types of conflicts that the United States currently faces or is likely to confront in the future.”¹⁰⁵ But asymmetric warfare and low-scale contingency operations, similar to though not exactly the same as U.S. counterinsurgency operations in Iraq and Afghanistan, were actually envisioned as a key part of the future conflict environment. The ability to dominate across the full spectrum of warfare was deemed so important, in fact, that it was part of the one-sentence statement of General Shinseki’s original Army Vision: “Soldiers on point for the Nation [transforming the most] respected army in the world into a strategically responsive force that is dominant across the full spectrum of operations.”¹⁰⁶ Full-spectrum dominance was understood to be as important as strategic responsiveness.

Early documents framed “asymmetric warfare” as a seminal part of the future strategic landscape, predicting that the threat would “make maximum use of complex and urban terrain and asymmetric techniques that may impact on our capability to maintain total situational understanding and/or employ long range fires or precision munitions.”¹⁰⁷ Subsequent though still early requirements documents were equally prescient about the nature of the threat. The O&O, for instance, acknowledged that enemy forces would “deliberately mix with local populations to avoid identification and to facilitate close-in attacks and ambushes” in complex terrain and urban structures. Furthermore, “movement will be executed as small mounted elements, or in dismounted fashion over a sequence of short distances” and “will be masked amongst non-combatants”—hugging tactics—“to further complicate our targeting abilities.”¹⁰⁸ The adversary’s offensive tactics, meanwhile, will be “opportunistic,” using a “combination of older but still lethal technologies and state-of-the-art high tech weapons.” Opponents will be able to close “undetected with FCS forces, often employing low-signature weapons,” which “deliberately raises the level of ambiguity with the goal of slowing the pace of FCS maneuver, therefore making it still more vulnerable.”¹⁰⁹ The description comes remarkably close to the insurgent threat that U.S. forces faced in Iraq and Afghanistan.

¹⁰⁵Krepinevich and Montgomery, July 2009, p. 1.

¹⁰⁶Shinseki, 1999.

¹⁰⁷U.S. Army, “Draft Mission Needs Statement for Future Combat Vehicle (FCV) Capability,” January 23, 2000, pp. 2–3.

¹⁰⁸UAMBL, “TRADOC Pamphlet 525-3-90/O&O,” July 22, 2002.

¹⁰⁹UAMBL, “TRADOC Pamphlet 525-3-90/O&O,” July 22, 2002.

FCS Forces Were Optimized for MCO and Expected to Dominate the Full Spectrum of Potential Conflicts

Though not optimized to fight such adversaries, FCS forces were intended to be able to dominate asymmetric warfare should the need arise. The FCS Unit of Action was designed to achieve “strategic preclusion” by maximizing “rapid force projection and mobility capabilities” and by allowing forces to arrive in time to deter or interrupt conflict escalation.¹¹⁰ But once engaged, “should an opponent not concede early,” FCS forces would be required to achieve overmatch “against any level threat,” high or low intensity, “in any region in sustained, decisive combat operations.”¹¹¹ However, this pivotal caveat created tension in the FCS operational concept: while it was optimized for major combat operations (MCO) against high-tech adversaries, it would have to be equally prepared for asymmetric operations on the other end of the spectrum of conflict. Moreover, while its lightweight design would theoretically optimize its capacity to achieve strategic preclusion by rapid deployment, that same design left it inherently disadvantaged in combat, low-intensity or otherwise. Advanced sensor and networking technology were, at least in theory, capable of offsetting this disadvantage by enabling near-perfect situational awareness and long-range lethality, but assuming those technologies would work exactly as intended left little room for error.¹¹²

The Army officials we spoke with were aware of the tension between the primary and secondary mission sets that FCS was intended to fight, often stating that the tension was resolvable. The 2008 Army Modernization Strategy, for instance, explained that, “Although optimized for offensive operations, the FCS BCT will be capable of executing full spectrum operations.”¹¹³ Yet FCS program officials never explained exactly how this was realistically possible. Instead, the program appeared to rely on the assumption that if FCS forces were sufficiently advanced to overwhelm high-tech opponents, they would, essentially by default, be able to fight against lower-tech and presumably less capable opponents. The October 1999 White Paper, “Concepts for the Objective Force,” reflects that assumption:

¹¹⁰U.S. Army, “Draft Mission Needs Statement for Future Combat Vehicle (FCV) Capability,” January 23, 2000, p. 1.

¹¹¹U.S. Army, “Draft Mission Needs Statement for Future Combat Vehicle (FCV) Capability,” January 23, 2000, p. 1.

¹¹²It is important to note, as a number of former FCS requirements officials emphasized, that contrary to popular belief, the FCS operational concept did not assume or require perfect intelligence or situational awareness. Although it required highly precise information, “unprecedented situational awareness and understanding,” and above all the ability to “see, understand and act first, then finish decisively,” the degree of intelligence it assumed was never described as “perfect.” TRADOC, “Change 1 to Pamphlet 525-3-90 O&O,” November 25, 2002, pp. 6-14 to 6-17.

¹¹³Lieutenant General Stephen M. Speakes, “2008 Army Modernization Strategy,” Washington, D.C.: Department of the Army, July 25, 2008, p. 69, cited in Krepinevich and Montgomery, 2009, p. 7.

The [Objective Force] will be designed for full spectrum success while optimized for major theater war. The force design means that formations will possess the *inherent versatility* [emphasis added] to operate effectively anywhere on the spectrum of military operations without substantial augmentation to perform diverse missions within a single campaign . . . These units will possess the lethality, speed and staying power associated with heavy forces and the agility, deployability, versatility, and close combat capability of today's light forces.¹¹⁴

The key phrase is “inherent versatility,” reflecting the attitude that force design optimized for major theater war would be inherently capable of effective operation in any conflict environment.

“See First, Act First” Concept Underestimated Technical Hurdles and Operational Applications in Non-MCO Warfare

Tension in the operational concept between the needs for both MCO and asymmetric warfare capabilities led to tension in a number of important requirements. In the original SoRC, a key requirement is for FCS to “provide near-real time combat identification of friend, foe and noncombatant across the spectrum of operations.”¹¹⁵ Like the C-130 deployability requirement, unprecedented tactical intelligence underpinned the FCS operational concept. As a 2001 Objective Force White Paper articulated, at the tactical level, FCS forces would “see first, understand first, act first and finish decisively as the means to tactical success.”¹¹⁶ By detecting, identifying and tracking enemy units and developing a “common operational picture (COP),” or detailed understanding of the enemy's capabilities and intent, FCS forces would, as the concept assumed, be able to achieve rapid battlefield dominance before the adversary had a chance to gain the initiative.

Armor-for-Information Tradeoff Was Thought to Enable Unprecedented Survivability, Not Perfect Intelligence

Information dominance, as a result of presumed future technological breakthroughs, was thought to enable operational dominance and “decisive victory” from standoff distances.¹¹⁷ This capability would allow MGVs to achieve levels of survivability equivalent

¹¹⁴U.S. Army Objective Force Task Force, “Objective Force White Paper: Concepts for the Objective Force,” October 2001, p. 11.

¹¹⁵UAMBL, “Statement of Required Capabilities,” 2001, p. 9.

¹¹⁶U.S. Army Objective Force Task Force, “Objective Force White Paper: Concepts for the Objective Force,” October 2001, p. 6.

¹¹⁷U.S. Army Objective Force Task Force, “Objective Force White Paper: Concepts for the Objective Force,” October 2001, pp. 7–8.

to that of modern tanks with only a fraction of the armor. It was a critical assumption that, like the C-130 requirement, tied together the underlying concept, theoretically enabling the development of vehicles that were not only lightweight but also lethal and survivable. Yet it was also one of the weakest premises of the program.

To be sure, as a number of interviewees emphasized, FCS was never intended to achieve “perfect” intelligence. This was a common misperception.¹¹⁸ The O&O Plan recognized that “uncertainty and time” would preclude commanders from achieving perfect situational awareness before deciding and acting.¹¹⁹ While not “perfect” intelligence, the “synchronized network of organic and links to external sensors” would nonetheless give the commander “reasonable certainty about the environment where he would be operating.”¹²⁰ But the distinction between “perfect” and “near perfect,” as an early requirements document phrased it, was not always clear.¹²¹ In the 2002 O&O Plan, for instance, the caveat that situational awareness need not be perfect is articulated in a single scenario toward the end; whereas earlier, the “Battle Command” section requires that “updates to the COP provide the commander with a real time ‘view of the battlefield’ with no appreciable difference between COP and tactical reality.”¹²² To achieve the critical “quality of firsts”—act first, understand first, act first, and finish decisively—that underpinned the FCS operational concept, tactical intelligence, whether perfect or just near perfect, would have to achieve revolutionary precision and reliability, the technological basis for which was largely unknown and unverified.

Differences Between Tactical Intelligence Requirements for MCO and Non-Conventional Warfare Were Underappreciated

While near-real-time intelligence, surveillance, and reconnaissance (ISR) capabilities would prove difficult enough in any scenario, requirements for high levels of situational awareness and understanding did not sufficiently appreciate differences in distinguishing between friendly, neutral, and adversarial forces in different types of conflicts. In a counterinsurgency environment, for instance, adversaries’ capabilities and intentions are rarely as easy to identify as a tank on a battlefield.¹²³ While the “determination of ‘force capability’ can be very difficult,” as a former program official wrote in an unpub-

¹¹⁸ Interview with TRADOC official, April 12, 2011.

¹¹⁹ UAMBL, “Change 3 to TRADOC Pamphlet 525-3-90,” December 16, 2005, p. H-25.

¹²⁰ UAMBL, “Change 1 to TRADOC PAM 525-3-90 O&O,” November 15, 2002, p. F-8.

¹²¹ TRADOC Analysis Center (TRAC), “Future Combat Systems Mission Needs Analysis (FCS MNA),” TRAC-F-TR-02-013, 2002, p. C-7.

¹²² UAMBL, “Change 1 to TRADOC PAM 525-3-90 O&O,” November 15, 2002, p. 4-26.

¹²³ Lawhern, 2009, p. 11.

lished outbrief on FCS, “assessment of actual ‘intent’ is for the most part imprecise or impossible”—particularly in an urban combat environment.¹²⁴

The Defense Intelligence Agency (DIA), which reviewed final versions of the ORD, noted in comments attached to the 2005 version that FCS requirements did not appreciate important differences between tactical intelligence on conventional versus unconventional adversaries. A DIA reviewer noted:

UAMBL still appears to assume that ability to detect, positively identify, and decisively, engage modern conventional mechanized forces in a ‘MCO’ environment will inherently ensure ability to detect, positively identify, and decisively engage irregular/insurgent forces hiding among and fighting from among civilian populations, often in urban or rural village environments.¹²⁵

The DIA added that “[relying] on information as the cornerstone for achieving a decisive overmatch of enemy forces’ [quoted from section 2.2.4 of the ORD] creates an insatiable and unrealistic requirement for extremely detailed real-time intelligence about identities, capabilities, and intentions.”¹²⁶ In response, however, UAMBL replied that the review was for KPPs only, and that the ORD does not assume FCS intelligence capabilities would ensure the detection and identification of all threats. The ORD requirements set high standards for situational awareness, but they did not recognize inherent limits to achieving it in the different types of conflicts in which FCS forces were expected to dominate. It is unclear why exactly this apparent assumption persisted, but it is likely that it resulted at least partly from overconfidence in the sophistication of the presumed technologies that would come out of the program.

¹²⁴Lawhern, 2009, p. 11.

¹²⁵UAMBL, “Operational Requirements Document for the Future Combat Systems,” 2005, pp. B-60 to B-62.

¹²⁶The JS/J2 and DIA review adds: The ORD

needs to better recognize the differences between operating against conventional, mechanized threat forces and irregular/insurgent/terrorist forces, especially regarding threat/target detection/ positive identification. ORD creates an unsupportable range of survival information intelligence requirements for highly granular, real-time threat recognition, positive ID, and tracking down to the lowest sub-tactical echelons (individual platforms/squads) . . . UAMBL still appears to assume that ability to detect, positively identify, and decisively, engage modern conventional mechanized forces in a “MCO” environment will inherently ensure ability to detect, positively identify, and decisively engage irregular/insurgent forces hiding among and fighting from among civilian populations, often in urban or rural village environments. The compactness and lethality of modern infantry weapons in the hands of irregulars or non-conventional forces who can get within lethal range of an FCS component without revealing themselves as armed/hostile, is a very severe challenge to the FCS Con Ops. The intelligence community lacks the ability to consistently detect, and positively identify, irregulars or hidden bombs in densely populated areas.

UAMBL, “Operational Requirements Document for the Future Combat Systems,” 2005, pp. B-60 to B-62.

Expert Assessments That Questioned Core Requirements Were Sometimes Liberally Interpreted

As the previous section suggests, ISR requirements for FCS were ambitious but ultimately unrealistic. Part of the reason for this is that expert technical assessments were sometimes underutilized as TRADOC was developing requirements. Again, the C-130 transportability requirement is an instructive case study. At several points before JROC approved the original version of the ORD in April 2003, airlift experts warned that designing the manned systems to the upper limit of C-130 payload capacity would severely undermine C-130 airlift capabilities. However, the 19-ton weight limit that TRADOC eventually settled on, beginning with the April 2003 ORD, fell within a range that airlift experts had repeatedly identified as problematic.

Experts Warned Against Setting the Weight Limit for FCS Manned Vehicles So Close to the C-130 Maximum Payload Capacity

There were at least four recorded instances before UAMBL finalized the written ORD requirements, beginning as early as March 2001, when airlift experts cautioned against pushing too far against the C-130's payload weight limit. The Army did not settle on 19 tons as a threshold limit until after January 2003, but up until this point had considered a number of different operational ranges as threshold and objective metrics for the requirement.

1. In June 2002, the Military Traffic Management Command Transportation Engineering Agency (MTMCTEA) warned that building the MGCV to 38,000 pounds or greater would severely limit C-130 airlift capabilities in less-than-ideal conditions.¹²⁷ In hot or high-altitude conditions, for instance, the range of an unarmored C-130 E/H, which comprises the vast majority of the Air Force's C-130 fleet, would be considerably restricted if it were carrying 38,000 pounds of payload or more. Hot *and* high-altitude conditions would potentially reduce that range to zero.¹²⁸ Likewise, assault landings stress C-130 airframes and imply maximum payload weights independent of any other factor. For a C-130 E/H with add-on armor, normal for combat missions, and no reserve fuel, the maximum payload was 36,000 pounds; if the C-130 E/H carried reserve fuel, which is also normal if a plane has to divert from its planned route for any

¹²⁷Military Traffic Management Command Transportation Engineering Agency (MTMCTEA), *C-130E/H/JJ-30 Transportability of Army Vehicles*, Newport News, Va.: MTMCTEA, June 28, 2002, p. 6. The June 2002 report is the first revision of MTMCTEA's March 15, 2001, White Paper, "C-130 Transportability of Army Vehicles," which we were unable to locate.

¹²⁸The report uses the example of an unarmored C-130 E/H with a 38,000-pound payload. The range of that aircraft taking off from Denver, elevation 5,431 feet, with otherwise ideal conditions, would be 275 miles round-trip. MTMCTEA, *C-130E/H/JJ-30 Transportability of Army Vehicles*, 2002, p. 6.

- number of reasons, the maximum cargo weight would fall to no more than 34,000 pounds.¹²⁹
2. In August 2002, MTMCTEA cautioned that, based on the historical patterns of weight growth of most major U.S. Army combat systems since 1970, FCS requirements developers should “plan for weight growth increases of 25% over the life of their system.”¹³⁰ Even a relatively conservative weight increase of 12.5 percent would take the FCS MGV well over the C-130’s maximum payload. For instance, if a 38,000-pound vehicle grew by 12.5 percent, the range of a C-130H, even assuming ideal conditions, would be only 30 NM; for a more realistic 25 percent weight increase, the range would be zero.¹³¹
 3. In September 2002, the LSI released a study recommending that the MGV be restricted to either 13.7 or 15.2 tons, depending on the average proximity of the nearest airbase with extra fuel, in order to be deployable via C-130 to at least 1,000 NM.¹³² The study did not assess maximum ranges under nonideal conditions for a C-130 with 38,000 pounds of payload, since that weight limit was not yet an active requirement, but it cautioned against pushing up too far against C-130 maximum payload capacities.¹³³
 4. In mid-April 2003, MTMCTEA released a Milestone B transportability assessment for FCS, based partially on its earlier reports.¹³⁴ It cautioned that “Designing the FCS vehicles at an upper weight limit for C-130 transport leaves no room for airfields not at sea level or 59 degrees F. In other words, the vehicles may not be C-130 transportable in high/hot locations such as Afghanistan.”¹³⁵ Moreover, the contractor-estimated weights of the FCS manned vehicles, at partially disassembled Essential Combat Configuration (ECC) weights starting at 22.5 tons, the MGV “will not be capable of C-130 internal air transport.”¹³⁶ The memo reiterated that “weight growth of the FCS vehicles over their life cycles

¹²⁹MTMCTEA, *C-130E/H/J/J-30 Transportability of Army Vehicles*, 2002, pp. 10–12.

¹³⁰MTMCTEA, *Historic Weight Growth of U.S. Army Combat Vehicles*, Newport News, Va.: MTMCTEA, August 27, 2002, p. 11. The study tracked the historical weight growth of the M113-series Armored Personnel Carrier; M2/3-series Bradley Fighting Vehicle System; M60-series Main Battle Tank; M1-series Main Battle Tank; and High Mobility Multipurpose Wheeled Vehicle (HMMWV).

¹³¹MTMCTEA, *Historic Weight Growth of U.S. Army Combat Vehicles*, 2002, p. 11.

¹³²Larry Glicoes, “Future Combat Systems (FCS): Transportability Report/Transportability Assessment Volume 1 of 2,” unpublished Boeing report, September 27, 2002, pp. E-4, E-5.

¹³³Also, it should be noted that the ORD range requirement in the first ORD was 250 NM (Threshold) and 500 NM (Objective) for the C-130, not 1,000 NM.

¹³⁴Military Traffic Management Command Transportation Engineering Agency, *Transportability Assessment of the Future Combat Systems (FCS) for Milestone B*, Newport News, Va.: MTMCTEA, April 23, 2003.

¹³⁵MTMCTEA, 2003, p. 9.

¹³⁶MTMCTEA, 2003, p. 9.

is likely,” which would render all of the vehicles, at their current contractor-estimated weights, nontransportable by any type of current C-130 aircraft.¹³⁷

Skepticism regarding the FCS C-130 transportability requirements may help explain why the metrics for deployability fluctuated significantly during the months leading up to Milestone B. An initial July 2002 draft ORD had no range or weight requirements at all.¹³⁸ An August 2002 ORD draft specified a minimum 750 NM range for C-130 aircraft carrying FCS, as long as fuel was available within a 250 NM radius of the delivery point.¹³⁹ Five months later, an Army Requirements Oversight Committee (AROC) approved ORD listed the range threshold as 500 NM under ideal conditions.¹⁴⁰ None of these draft versions of the ORD mentioned a specific weight limit.

Underutilization of expert judgment in the early stages of the FCS program was a problem that seemed to go beyond the C-130 requirement, however. The Distribution/Coordination Records, appended as Appendix B to each of the three JROC-approved versions of the ORD, indicate that the draft ORDs were widely distributed for critical feedback from subject matter experts and the user community before being sent to the JROC for final approval. Although some of the editorial comments addressed administrative edits, such as spelling errors, or were otherwise narrowly focused, many were substantive in nature and spoke to apparently important flaws in the requirements. During the review process for the 2005 version of the ORD, for instance, two reviewers noted that the combined KPPs provided “little or no trade space to the material developer, indicated significant risk of satisfying all KPPs within the increment one delivery.”¹⁴¹ In response, UAMBL noted that the KPPs were challenging and would evolve through an iterative process. (Ultimately, few KPPs adjusted significantly, and two, survivability and networked battle command, did not change.) The annexes indicate that critical feedback did not lead to revisions of many ORD requirements. UAMBL responded to many comments by restating passages of the ORD that reviewers deemed unclear or erroneous, or by referring to orders that effectively invalidated suggestions from reviewers.

This may point to one of several potential conclusions about how expert technical input was integrated into the requirements generation process: (1) the review process did not occur early enough in the process to be effective; (2) the timing of the review

¹³⁷MTMCTEA, 2003, pp. 8–10.

¹³⁸UAMBL, “Operational Requirements Document (ORD) for the Future Combat Systems (FCS),” Pre-Decisional Draft (v 0.98), Fort Monroe, Va.: UAMBL, July 20, 2002.

¹³⁹UAMBL, “Operational Requirements Document for the Future Combat Systems,” Draft, Fort Knox, Ky.: UAMBL, August 30, 2002, pp. 38–39.

¹⁴⁰UAMBL, “Operational Requirements Document for the Future Combat Systems,” Change 2 (AROC Approved), Fort Knox, Ky.: UAMBL, January 22, 2003.

¹⁴¹UAMBL, “Operational Requirements Document (ORD) for the Future Combat Systems,” January 31, 2005.

was appropriate, but the requirements were too inflexible by the time it occurred; or (3) the expert reviewers had too little influence on the requirements relative to the requirements developers, and the latter had no obligation or forcing mechanism to accept or integrate the critical feedback. However, problems integrating expert advice most likely stemmed from all three of these factors.

FCS Operational Requirements Were Sometimes Inconsistent with Requirements of Key Complementary Systems

FCS depended critically on a number of external, complementary systems. But FCS requirements were sometimes at odds with requirements for its complementary systems in ways that would have critically undermined FCS technically and operationally. A number of key FCS requirements were inconsistent with those of the JTRS and the WIN-T, two of the largest and most important enabling complementary programs, in ways that would have made the systems non-interoperable and prevented the FCS from establishing a network, which was pivotal to achieving the underlying operational concept.

JTRS Ground Mobile Radios (GMR), for instance, specified an environmental range outside of which it would not be able to function that was significantly narrower than the range required in the FCS ORD.¹⁴² These inconsistent requirements meant that, without steps to reconcile the two system designs, the backbone MGW communications platform would not have been expected to function within an interior temperate range (50–85 degrees Celsius) considered normal for FCS MGVs. Gaps in requirements between the FCS and the JTRS Handheld, Manpack and Small Form Fit (HMS) radios, expected to link soldiers, unmanned vehicles, and sensors to the FCS network, meanwhile, were even more serious. A number of major gaps in requirements between the two systems, including requirements specifying duty cycle, throughput, range, and latency, were identified as “show stoppers” to FCS.¹⁴³ FCS, for instance, specified particular ranges at which unmanned vehicles could communicate via JTRS, whereas JTRS requirements did not explicitly state range performance expectations.

At least one source of wide-ranging mismatches between FCS and complementary programs’ requirements was that they were written separately and without detailed reference to one another. Complementary programs also lacked both a mandate and funding to agree on interface specifications with FCS, that is, to ensure that their requirements were mutually consistent.¹⁴⁴ The major requirements that they needed JTRS and WIN-T to fulfill in order to allow FCS to function, including requirements describing how to form a network and tier networks down, were not in the contract

¹⁴²Interview with former program official, March 7, 2011; interview with former program official, February 2, 2011; FCS Program, “GMR Requirements GAP Discussion,” unpublished briefing slides, December 6, 2007.

¹⁴³FCS Program, “Gap Identification and Resolution: SRW,” unpublished briefing slides, December 6, 2007.

¹⁴⁴Interview with former program official, March 7, 2011.

for either of those programs.¹⁴⁵ Another issue, according to former program officials, is that managers from FCS and complementary programs spent an inordinate amount of time “bantering” over gaps in low-level, relatively insignificant requirements, but were unable to adjust requirements effectively without high-level support.¹⁴⁶ With such a large number of complementary programs with their own requirements, in addition to an already unwieldy set of requirements for FCS alone, it may have been unrealistic for FCS officials to manage all of them effectively.¹⁴⁷ Although FCS officials were aware of mismatched requirements early on and attempted a number of strategies for resolving the issue, they were unable to do so effectively. Several strategies included the establishment of a senior board with all Army stakeholders; a community of interest between FCS and JTRS and WIN-T, arguably the most critical complementary programs; and various Memoranda of Understanding between FCS and the complementary programs to improve integration.¹⁴⁸ But effective relationships with complementary programs were difficult to establish, and none of these methods solved the problem.

Tensions Between Unreconciled FCS Requirements and Complementary Program Requirements Created Burdens for Engineers

For engineers working on complementary programs, however, modifying their requirements to match with FCS sometimes represented an impossible burden. Ammunition developers, for instance, as a result of being subordinated to FCS as a complementary program, were given a requirement from FCS that all ammunition be able to survive high-altitude electromagnetic pulse.¹⁴⁹ From the perspective of many ammunition engineers, however, this requirement was unreasonable, and expending limited resources to try to achieve it would be excessively costly and impractical. Although LSI officials and ammunition developers eventually managed to resolve the requirements mismatch with an MOA between the two programs, this did not occur until 2009, a full six years after the requirements were written.¹⁵⁰ The prolonged period of time that it took the program to make a relatively uncontroversial exception to a requirement also illustrates the related problem that requirements were too slow to change, too

¹⁴⁵ Interview with former program official, July 7, 2011.

¹⁴⁶ Interview with former program official, February 22, 2011.

¹⁴⁷ Interview with former program official, July 7, 2011. A major reason why there were so many complementary programs is that, across the Army, acquisition programs needed to demonstrate association with FCS in order to continue to receive funding. From a requirements perspective, this resulted in an unreasonably large number of requirements that FCS managers had to synchronize with FCS, despite the fact that the vast majority of complementary requirements were not critical to FCS design.

¹⁴⁸ Interview with former program official, June 10, 2011; interview with former program official, July 7, 2011.

¹⁴⁹ Interview with former program official, March 16, 2011.

¹⁵⁰ Interview with former program official, March 16, 2011.

infrequently, an issue that a subsequent section of this chapter will discuss in greater detail.

Technical Analysis of Most Requirements Did Not Take Place Prior to Milestone B

Considering the unprecedented size and complexity of the FCS requirements, thorough analysis of the requirements prior to Milestone B was astonishingly thin. As a result, key requirements, including KPPs and threshold requirements directly underpinning KPPs, were not comprehensively analyzed until after they were written, approved by top-level acquisition boards, and set in place to drive the entire FCS program. While TRADOC apparently carried out a great deal of early, operational analysis, which laid the intellectual foundation for FCS concepts and analysis of alternatives, meticulous analysis of technical feasibility was habitually inadequate.¹⁵¹ There were a number of reasons for this analytical shortcoming, perhaps most important the compressed timeline for generating requirements between November 2001, when the program down-selected to a single contractor, and April 2003, when the JROC approved the first ORD. A major problem, highlighted in several slides presented to the Vice Chief of Staff of the Army in 2009, was that the program “rushed to failure” at Milestone B before it had solid analytical underpinnings for all of the requirements indicating that the technologies were achievable.¹⁵²

Compressed Timeline and Confusion Surrounding Technical Feasibility Verification Created Significant Problems

Failure to analyze requirements thoroughly resulted from at least two factors: insufficient time, and a confusion of roles. UAMBL began drafting ORD requirements in March 2002, when Boeing/SAIC was selected as the LSI, completed a 172-page predecisional draft ORD containing over 550 requirements by mid-July, and determined threshold and objective requirements by late August.¹⁵³ For the Army’s largest acquisition program and set of requirements ever, this was a remarkably short timeline. Although there was concern within UAMBL that many requirements were not underpinned by sufficient technical analysis, UAMBL relied on DARPA to execute this role.¹⁵⁴ The problem, however, was that DARPA is not an acquisition organization, and requirements analysis is not one of its core capabilities, and so it was underpre-

¹⁵¹ U.S. Army, “FCS AAR,” unpublished briefing slides, June 3, 2009; interview with TRADOC official, April 12, 2011.

¹⁵² U.S. Army, “FCS AAR,” 2009.

¹⁵³ Interview with TRADOC official, April 12, 2011.

¹⁵⁴ Interview with TRADOC official, April 12, 2011.

pared and unable to conduct thorough requirements analysis, particularly in such a short period.¹⁵⁵

Unit Design and Detailed Architecting Sometimes Began Before Operational Requirements Were Settled

Due to the compressed timeline before Milestone B, the requirements community was forced to leap into unit design while they were still flowing down and decomposing requirements. What this meant, as several former program officials recalled, was that engineers began designing and in some cases even building systems before they knew exactly what they were required to build. In this environment, there was apparently no systematic method of assessing whether unit-level capabilities were meeting brigade- and SoS-level requirements.¹⁵⁶ Following Milestone B, as many requirements and specifications adjusted, engineers were forced to backtrack and alter their designs, a costly and time-consuming process that could have been avoided with more time for thorough analysis prior to Milestone B.

Conclusions and Lessons

Conclusions

As with any major defense acquisition program, requirements drove the Future Combat Systems from inception to termination and decisively affected its outcome. That the requirements were flawed in some respects does not detract from a number of important strengths. Both positive and negative dimensions of the FCS requirements story bear equally important lessons for future acquisition programs. In general, however, evidence from hundreds of requirements documents and dozens of interviews with program officials suggests that requirements ultimately limited the program's success. Many of the most critical requirements to fulfilling the operational concept also carried the highest risk. In addition, operational requirements were insufficiently analyzed and were not written to optimize flexibility to achieve system-of-systems capabilities at the brigade level, and an ill-defined architecture left a gap in system design between operational concepts and technical capabilities.

Lessons

Moving forward, FCS provides a number of critical lessons that the Army can absorb as it continues to develop new acquisition programs from a unit-based perspective and system-of-systems and network-centric designs.

¹⁵⁵ Drezner, untitled draft monograph, 2005.

¹⁵⁶ Interview with former program official, June 10, 2011.

An O&O plan that takes an integrated unit perspective can aid requirement formulation. As a number of former FCS officials noted, from a requirements perspective, perhaps the most useful lesson from the FCS program was that its brigade-level perspective enabled a number of useful approaches to designing concepts, and requirements flowed from this critical starting point. Most significantly, FCS engendered an innovative framework for developing brigade-level requirements, even if some flaws within that framework ultimately prevented it from succeeding in the ORD. Organizationally, UAMBL and the requirements integration process that it spearheaded, though imperfect, provide a foundation for generating SoS requirements for future integration efforts. UAMBL's consolidated team drew from proponent commands across the Army and attempted to break down stove-pipes that typically define the requirements generation process.

Moreover, TRADOC started with a concept of integrated, network-centric operational maneuver, and spelled out in the O&O Plan how component systems and sub-systems would interoperate in different types of warfare. The O&O Plan usefully served as a key reference point throughout the program as requirements were developed, decomposed, and refined over time. Many interviewees described the O&O as an important step in the right direction, highlighting it as a useful model for acquisition programs of similar size and complexity in the future.

A successful program requires a sound technical feasibility analysis. Despite its value, the O&O Plan was compromised by an overreliance on assumptions that the acquisition community could develop and integrate items using state-of-the-art technologies.¹⁵⁷ This, in addition to equally optimistic expectations that unprecedented and technically underanalyzed deployability, ISR, and intelligence fusion capabilities would be achieved, should have served as early warnings of how reliant the program was on critical, high-risk assumptions. Predicating the program on this capability created a critical weakness, with little room for graceful degradation of capabilities to achieve marginally more useful capabilities.

The two key assumptions that held together the operational concept, C-130 transportability and real-time, tactical intelligence, also had the weakest technical bases. The most important capabilities, in other words, also carried the highest risks. While this demonstrates the danger of relying on high-risk but critical assumptions, it also illustrates the absence of leeway for graceful degradation. The operational concept was so dependent on C-130 transportability and tactical "omniscience" that it collapsed when these two capabilities could not be achieved. As a result, it provided no utility, based on what it was intended to achieve, rather than slightly less utility. This is not to say that lighter-weight vehicles would have been useless to the Army if they could not fit

¹⁵⁷ UAMBL, "TRADOC Pamphlet 525-3-90/O&O," July 22, 2002, p. 13. The O&O Plan listed as the first key assumption on which the Unit of Action O&O development was based: "The acquisition community will be able to deliver required technologies" and "resources will be available."

on a C-130; indeed, the assumption that they would have significant utility otherwise helped justify the persistence of extremely difficult but ultimately infeasible transportability requirements. But without C-130 transportable vehicles, innovative concepts of vertical envelopment were unworkable, eliminating a major source of operational value that FCS promised. Likewise, limited faith that the network could achieve sufficient levels of situational awareness and understanding to compensate for heavy armor led to a reluctance within the Army fully to embrace the “quality of firsts” and abandon traditional, physical means of force protection. Without highly reliable ISR and networking capabilities, the information-armor tradeoff that theoretically enabled lightweight vehicles also to be highly survivable simply did not work.

A more practical approach might entail earlier, more rigorous analysis of technological forecasts, assumptions, and the operational environment, all of which feed into the O&O Plan. A more cautious approach might simply ensure that revolutionary concepts remain just that, concepts, until underlying technical assumptions have a firmer basis in reality. The O&O Plan listed all of its major assumptions; it may have been useful to add to this list the relative strengths and weaknesses of those assumptions, what variables could weaken them, and how that would affect the military utility of the O&O. Another lesson is that, depending on how quickly the Army wants to field a system, the most critical, technical linchpins enabling the operational concept should not also be the riskiest. Similarly, if such requirements are technically ambitious, their utility should be scalable (rather than binary) so that they can enable the operational concept, to some lesser though still practical degree, even if not fully realized.

A specific approach is for the Army requirements community to increase their use of independent evaluators or “red teams” to test requirements while in development, and well before and in the leadup to Milestone B.

The development of operational requirements requires an integrated, unit-level (not system-level) approach. Despite organizational integration at the combat development level, requirements were not ranked hierarchically early enough, and system-level capabilities were not effectively subordinated to SoS-level ones. Moreover, the large number and specificity of system-level requirements prevented many trades to meet SoS-level requirements and constrained the structure of the architecture. FCS requirements developers initially used the Interim Armored Vehicle (Stryker) ORD as a model, because it was “crisp, not restrictive” and “[did] not contain performance specs.”¹⁵⁸ But this lesson was lost as the FCS ORD was developed. Early, SoS-level descriptions, such as the O&O Plan, played a useful role by describing the behavior and function of the brigade. But the ORD drew away from this nonrestrictive approach by focusing on individual systems and introducing overly specific requirements with narrow and in some cases unrealistic parameters. Although the ORD contained several categories of

¹⁵⁸Major General James J. Grazioplene, “Concepts Based Requirements in Support of the Objective Force: Briefing to the AUSA Symposium,” unpublished briefing slides, November 8, 2001.

requirements, based on their importance to achieving SoS-level capabilities, ultimately they were all thresholds requirements and had the same implicit level of prioritization.

Insufficient analysis and mismanagement of expectations can lead to unrealistically ambitious requirements. These shortfalls resulted partly from the fact that the ORD was developed in a hurry, with too little technical analysis or understanding of how lower-level requirements would integrate in order to achieve higher-level ones. Since this was the largest integrated set of requirements the Army had ever developed, it was extremely difficult to analyze and understand precisely how all of them would interoperate. Compressing the amount of time allotted to reach such an understanding did not help. Equally problematic, from a requirements perspective, were the ambitious expectations that many officials built up to Congress and the public early in the program. A common grievance was that the “propaganda campaign” rapidly outpaced delivery, making it difficult for program officials to backtrack on promised capabilities and for the user community to relax requirements. The initial, 96-hour strategic deployment objective, for instance, set a high but unrealistic bar without a proper understanding of what exactly it meant for requirements and technologies. In the future, it may be wiser not to set expectations so high, so early, and so publicly, all of which helped make those promises irrevocable. Additionally, when requirements are set and driven at such a high level within the Army, it is that much harder to walk them back if necessary.

Complex system-of-systems acquisitions may require suboptimization of systems to achieve optimized higher-level unit optimization. The UAMBL, while integrated organizationally, did not effectively integrate requirements from a high-level, brigade perspective. While UAMBL controlled the ORD, proponent commands controlled many individual requirements that they were allowed to write more or less directly into the ORD. As UAMBL was composing the ORD, proponent commands introduced many overspecified requirements that, in many cases, UAMBL did not override and rewrite to open trade space critical to optimizing SoS-level performance. In this sense, UAMBL was unable to transcend the stove-piped Army bureaucracy that typically develops requirements only superficially. Effective generation of unit- and SoS-level requirements therefore demands tighter centralization and more hierarchical organization ranking SoS design and integration responsibilities and authorities clearly above individual systems and Army branches.

Parochial branch interests can hamper achieving overall unit capabilities. Army branches are used to writing requirements to optimize capabilities within their functional areas. But designing an integrated unit from the ground up necessitates prioritizing unit over individual system performance, and optimization of the brigade is rarely compatible with optimization of every individual component. If the Army is to embrace ground-up, SoS-based development of units rather than individual systems, combat developers at proponent commands will have to become comfortable with

prioritizing higher-level performance and functionalities above their own parochial interests and priorities.

A detailed description of integrated unit-level operations and functionalities can clarify how individual requirements interact and fit in the operational architecture. As our analysis suggests, tiering should be only the first step toward developing unit sets of requirements. As equally important issue was that, if the ORD suffered from excessive specificity, the O&O Plan suffered from exactly the opposite problem: too little specificity. In other words, while system- and subsystem-level requirements were too narrowly defined, brigade-level requirements were too vaguely defined. This created problems for engineers as they began to analyze and decompose the ORD following Milestone B. Often it was difficult to understand exactly how individual requirements interacted with one another and fit into the operational architecture, which was relatively underdeveloped and reportedly marginalized as the program focused on preparing the ORD for JROC approval to pass Milestone B.

A detailed and early operational architecture may connect operational requirements and unit-level concepts more tightly. As a number of engineers involved with the program pointed out, needed is a bridge between the O&O Plan and the ORD, in order to describe in greater detail how individual requirements are allocated, and how they interoperate and interact to achieve higher-level functionalities. Developing a unit-level set of requirements was clearly a step in the right direction, but what is also clear is that greater specificity was needed to describe to engineers what exactly TRADOC wanted the brigade to do, how it would fight, how integrated systems would interact, and how the network would operate. One solution, as a number of interviewees suggested, would be to spend more time developing an intermediate document between the O&O and the ORD that would describe integrated unit-level function with greater specificity. Although TRADOC fleshed out many of these details, generally this did not occur until after Milestone B. Since engineers had in many cases designed their own ad hoc architectures independently when they found the government's version too ill-defined, as TRADOC refined the architecture, the LSI frequently had to go back and change engineering solutions that it had already begun to develop, which helped drive schedule delays and cost increases in the overall program.

A refined operational architecture may have been useful in several other ways as well. First, if developed from the top down, starting with the SoS-level functions and then describing in greater detail how individual systems contributed to higher-level capabilities, a refined operational architecture bridging the O&O and the ORD could have helped combat developers discriminate between critical and noncritical requirements—in other words, tiering. Second, refined operational architecture could be equally useful for aligning requirements with complementary program and tiering those systems alongside internal program requirements. Third, as the following chapter will explore in greater depth, framing requirements more explicitly in a brigade-level, operational framework might also have helped combat developers assess the impact of

requirements changes as the FCS program passed through Milestone B into the SDD phase.

Designing smaller integrated units could facilitate the development of requirements for large systems of systems. Another practical solution might also be to decrease the size of the unit. Designing requirements for an entire brigade, as TRADOC found, was extraordinarily complex due to its size, the number of constituent systems, and the consequent scale of the network. The idea behind developing a more detailed operational architecture is to describe the complex behavior of the unit more exactly and thus reduce ambiguity about its design. Another approach to reduce design ambiguity would be to reduce complexity by narrowing the scale of the unit, for instance, by generating requirements for a company rather than a brigade.¹⁵⁹ If an integrated brigade is the ultimate objective, the Army could then simply determine how multiple companies come together to fulfill brigade-level capabilities. Whatever approach the Army takes, in unit size and other areas, small steps may ultimately be more fruitful than giant leaps.

¹⁵⁹Interview with former program official, August 16, 2011.

The Evolution and Adjustment of Requirements After Milestone B

This chapter presents the second half of the requirements story. It resembles the first in that it illustrates the danger of developing overly ambitious operational concepts that are underpinned by difficult technologies. This chapter explores how the 19-ton essential combat configuration weight limit for MGVs,¹ intended to enable C-130 transportability, was quickly identified as impossible but never officially changed. This chapter also examines the ways in which the FCS program failed to adapt to the rising IED threat and to the larger challenge of a counterinsurgency.

The C-130 Requirement Never Officially Changed

After Milestone B, as engineers grappled with how to pack hundreds of required capabilities into MGVs and maintain an acceptable level of survivability, estimates of overall vehicle weight gradually crept upward. When FCS passed Milestone B, not a single vehicle was projected to weigh less than 19 tons in either full combat capability (FCC) or essential combat configuration (ECC).

In June, the lightest vehicle at ECC was 21.5 tons: the Command and Control Vehicle (C2V). At FCC, it weighed 23 tons. The Mounted Combat System (MCS), on the other hand, came in at 23.8 tons at ECC and 27 tons at FCC, while the NLOC-C was estimated to weigh 25.3 tons at ECC and 29.2 tons at FCC.² The other five MGV variants all weighed 22–26 tons at ECC and 23–29 tons at FCC. These estimates were well over the 19-ton limit for C-130 transportability, and if the MGV was like every other armored vehicle the Army had ever developed, its weight was likely to increase further over these early estimates. While this likely growth was captured in LSI esti-

¹ ECC or essential combat configuration is defined in the AMSAA Systems Book for FCS as full basic load of ammo, 3/4 tank of fuel, crew, passengers, and equipment. FCC or full combat capability is defined as a full tank of fuel, wares for 72-hour operational tempo, and all ECC items.

² Manned Ground Vehicle IPT, "Manned Ground Vehicle (MGV) Requirements Trade Process Overview in Response to MGV Weight Challenges," unpublished briefing slides, Fort Knox, Ky., July 30, 2003.

mates of future MGV weights, the LSI predicted that it would be more than offset by weight-saving technologies and other methods to reduce ECC weight.

The FCC, Nondeployable Weight Limit for the MGV Was Adjusted Upward Several Times

In response to MGV weight growth, the Army gradually relaxed overall vehicle weight restrictions, understood as total vehicle weight at FCC. In June 2006, the Army had adjusted the FCC limit for the MGV common chassis to 24 tons, and revised it again to 27.4 tons in January 2008.³ At this point, however, the MGV design entered what engineers called a “death spiral,” as the higher weight allowances for armor, armaments, and other equipment necessitated a larger power pack and heavier suspension, adjustments which themselves added weight.⁴ These weights would have severely stressed the then estimated range of a C-130.

The Army soon adjusted the weight limit again to 30 tons, at which point the MGV design was realistic but still challenging. To accommodate the increased weight, engineers eventually developed designs for three different types of chassis. While this drew away from the Army’s emphasis on modular design, it was an appropriate trade considering the reality of expected, continued weight growth.

While Estimated Vehicle Weights Were Climbing Above 19 Tons, the Official 38,000-Pound MGV Limit Did Not Adjust

As the Army allowed the MGV weight to increase, however, the formal ORD requirement that the MGV would have to weigh no more than 38,000 pounds (19 tons) at ECC did not change. Changes at the program management level without formal approval and restating of requirements suggest a lack of a rigorous configuration management process. Experience indicates that complex programs containing many systems and subsystems require just such a process. Since the ECC weight limit did not change, increases in FCC weight allowances were interpreted to be consistent with C-130 transportability. As a result, the C-130 transportability requirement never changed, either. This is contrary to some reporting at the time that the Army had stepped off that requirement.⁵ While this may have been the popular interpretation within the Army, in reality, TRADOC never relaxed the 19-ton or C-130 requirements in the official ORD. Eventually TRADOC did eliminate the C-130 requirement and modified it to three MGVs to a C-17, but its recommendation to do so did not come until November 2007, at the same time that it advised changing the weight

³ Interview with former program official, February 11, 2011; “Schoomaker Tells FCS Office to Pursue 24-Ton Manned Ground Vehicles,” *Inside the Army*, June 6, 2005; William S. Wallace, “C-130 Transportability Requirement,” Memorandum for Chief of Staff, U.S. Army, January 7, 2008.

⁴ Interview with former program official, February 11, 2011.

⁵ Gant, “Rolling FCS into Reality,” 2005.

limit to 27.4 tons. TRADOC wrote the adjusted requirements into the Capability Development Document (CDD), which replaced the ORD as the program switched from the DOD 5000 series to the new Joint Capabilities Integration Development System (JCIDS). The CDD for FCS, however, remained in draft form and was never approved by either AROC or JROC. As a result, until the end of the FCS program in May 2009, 19 tons and C-130 transportability remained the official requirements.

As a result of the official MGV weight requirement not adjusting, other requirements adjusted. The acceptability of add-on armor, the 96-hour deployment timeline, and the amount of time allowed for transitioning FCS from ECC to FCC were the primary requirements that changed as the estimated FCC weight limit rose. An ORD requirement that had initially prohibited the application of add-on armor to ensure ballistic protection against small arms and 14.5mm machine guns, for instance, was edited in the 2006 ORD to allow for add-on armor.⁶ At the weight levels required to enable C-130 transportability, integral armor simply could not protect crew members and critical functionality against even relatively light weapons. (Stryker, by contrast, had integral armor that was 14.5mm resistant.) Add-on armor, however, would not be easy to apply, and doing so would significantly increase the amount of time and non-organic equipment required to reassemble, refuel, and rearm vehicles once deployed.

While FCC Estimates Grew, Requirements Deemed Less Important Than C-130 Deployability in ECC Were Adjusted to Preserve the 19-Ton ECC Weight Limit

For this reason, requirements limiting the amount of time and equipment FCS forces had to transition from essential to full combat capability also had to change. Originally, FCS vehicles were required to make this transition within a 30-minute threshold.⁷ By the third official iteration of the ORD, however, this transition window had lengthened to “4–6 hours with crew and passenger assistance” and “no more than one hour of MHE support per platform.”⁸ MHE stands for materiel (and generally mechanical) handling equipment, meaning that an MGV crew would be expected to use specialized, typically heavy tools to reassemble MGVs once deployed. Although the same requirement mandated that MGVs be able to deploy primary and secondary weapons and protective systems upon arrival, precise offensive and defensive capabilities are left unspecified. While a readily available level of fighting ability is assumed, considering the extensive tradeoffs made to achieve ECC weight, this level is clearly far lower than full FCC.

⁶ UAMBL, “Operational Requirements Document (ORD) for the Future Combat Systems,” April 27, 2006.

⁷ Manned Ground Vehicle IPT, 2003. UAMBL, “Operational Requirements Document (ORD) for the Future Combat Systems,” April 27, 2006 (ORD 1547).

⁸ Manned Ground Vehicle IPT, 2003.

UAMBL, “Operational Requirements Document (ORD) for the Future Combat Systems,” April 27, 2006 (ORD 1547).

At the same time as ECC-FCC transition time lengthened, the program also modified how it defined ECC, in order to allow MGVs to shed more weight (and capabilities) while technically retaining ECC for C-130 deployment. The initial O&O Plan, for instance, defined ECC as a full turret or fighting load of ammunition, a 3/4 tank of fuel, full crew and passengers, and immediate self-defense capabilities.⁹ Over the next two versions of the O&O Plan, however, UAMBL winnowed ECC requirements to 1/4 tank of fuel, sufficient ammunition for “limited defensive operations,” and an operating crew but no passengers.¹⁰ In 2005, MGVs in ECC were required to have ballistic protection against 14.5mm ammunition all around and 30mm rounds in front.¹¹ But changes to the final ORD four months later reversed this policy by implying that MGVs would be survivable against 14.5mm only with add-on armor, which could take up to six hours to apply. For those six hours, MGVs would be dangerously under-armored, at least according to the earlier standards of survivability.

Changes to the FCC weight limit for MGVs, though widely understood across the FCS program, were never clarified in official requirements documents. Several versions of the ORD and more than a dozen versions of system-of-systems specifications (SoSS) dealt explicitly only with ECC weight, even though FCC weight was creeping upward. This created a significant gap between the MGV design limits as articulated in official, JROC-approved requirements documentation and vehicle weight restrictions as understood within the Army. While engineers began building toward a 24-ton vehicle as early as 2005, for instance, and subsequently toward 27-, 30-, and 32-ton designs, these figures never appear in high-level requirements documents, despite their significance. This contributed to significant design instability, as FCS engineers continually readjusted weight estimates and negotiated higher weight limits with requirements officials piecemeal and bit-by-bit as the program continued, as opposed to clearly and in one fell swoop earlier in the program, when sufficient information arguably existed to cast doubt on even intermediate, mid-range estimates of realistic weight limits. As these upper weight limits changed, however, they were not codified in official requirements documents. Only ECC weight limits appeared in the ORD and the SoSS.

The adjustable FCC weight limit gave engineers flexibility to design MGVs within the bounds of physical and technological possibility, which was critical. On the other hand, without an upper limit to FCC weight codified in official requirements, total vehicle weight was allowed to grow in ways that, as changes to add-on armor and ECC-ECC transition thresholds demonstrate, created inconsistencies with concepts and requirements that had been initially designed around lower weight expectations. In another sense, the tension between continual weight growth and the officially unchanged C-130 requirement reflected a certain degree of cynicism that C-130

⁹ UAMBL, “Change 1 to TRADOC PAM 525-3-90 O&O,” 2002.

¹⁰ UAMBL, “Change 2 to TRADOC Pamphlet 525-3-90 O&O,” 2005.

¹¹ UAMBL, “Change 2 to TRADOC Pamphlet 525-3-90 O&O,” 2005.

deployability could actually be achieved, but also continued faith in its capacity to force engineering solutions that would reduce logistics burdens, boost fuel efficiency, and drive other desired innovations.

Changes in Requirements Related to ECC-to-FCC Transition Created Inconsistencies with Key Operational Concepts

Adjustments to ECC-related requirements were not always consistent with the overarching operational concept. For instance, lengthening the amount of time allowed to transition from ECC to FCC from 30 minutes to 4–6 hours conflicted with earlier, high-level requirements as well as with key operational concepts mandating that FCS be combat-capable quickly upon deployment. The 2000 draft MNS, for instance, articulated that

Immediately upon arrival in the area of operations, FCV equipped forces must be capable of fighting as units and individual FCV platforms must be fully operational and capable of carrying all vehicle crews, troops, cargo and supporting equipment.¹²

Likewise, the 2006 ORD explained that the FCS brigade should be “immediately capable of conducting distributed and continuous combined arms full spectrum operations, day and night, in open, close and complex terrain, throughout the battlespace, and without undergoing reception and staging.”¹³ Yet in the same ORD, the requirement that adjusted to enable C-130 deployability allowed up to six hours of reception and staging to apply add-on armor, fuel, and ammunition.¹⁴ This was a significant amount of time that not only stood at odds with the stated operational capabilities, but also seemed to degrade the FCS brigade’s military utility.

Deployability Concepts Were Degraded as They Were Relaxed to Enable 19-Ton ECC Vehicle Weight

The operational concept, as articulated in successive versions of the O&O Plan, also adjusted significantly to the lengthened ECC-FCC transition window. An early version of the O&O Plan, for instance, stated that MGVs would have to be capable of (a) upgrading to FCC, (b) conducting full-spectrum operations, and (c) adding on

¹² U.S. Army, “Draft Mission Needs Statement for Future Combat Vehicle (FCV) Capability,” 2000, p. 5. At 27 tons, the MGV entered a “design spiral,” where the rising weight of the vehicle required a more powerful propulsion system, stronger suspension, and other, heavier components to support the increasing weight of the MGV.

¹³ UAMBL, “Operational Requirements Document (ORD) for the Future Combat Systems,” April 15, 2003.

¹⁴ UAMBL, “Operational Requirements Document (ORD) for the Future Combat Systems,” April 27, 2006, p. 7.

capabilities like enhanced mine survivability and add-on armor, all within 15 minutes of arrival.¹⁵ A subsequent, June 2003 version loosened the requirements so that FCS forces could carry out all three transitions “within [unspecified] minutes of arrival,” and a third, December 2005 version deleted that sentence altogether.¹⁶ All three versions also explain that the “operational concept is to ‘fight on arrival’ without traditional support requirements.” But each caveats that this “does not mean the platforms must ‘fight off the ramp’ as they are being unloaded,” but that they are “prepared to quickly fight once unloaded” and even in ECC are “immediately capable of self-defense and integration into the C4ISR network.”¹⁷

But it is difficult to see how MGVs would be prepared to fight and defend themselves (the minimum requirement) if given six hours to add applique armor and other capabilities, not to mention the actual crews themselves, who would by necessity arrive on separate aircraft. Notably, the operational concept of “‘fighting on arrival’ without traditional support requirements,” though central to the original concept, was deleted from the final version of the O&O Plan.¹⁸ The modification illustrates how the operational concept was repeatedly adjusted to meet the C-130 deployability requirement, whereas the intent of developing a brigade-level O&O Plan was for the concept to shape the requirements, rather than the other way around.

Relaxing Limits on How Vehicles Would Transition from ECC to FCC Undermined the Operational Value of FCS

Since FCS was intended to achieve rapid operational deployment with combat-ready capabilities, the extension of ECC-to-FCC transition time undermined the system’s original, core operational and strategic concepts and, by extension, its underlying value to the Army. Vertical envelopment, i.e., an assault from the air, for instance, no longer seemed as tenable an operational concept. Extending ECC-to-FCC transition time to six hours implied that intratheater transport aircraft would be unable to emplace FCS forces any nearer than six hours from the adversary’s closest forces. The latter could use that significant window of time, while MGVs would presumably remain incompletely armed, armored, or manned, to attack first and preempt offensive maneuvers by an FCS-equipped brigade. Being forced to land FCS forces so far out of contact with the enemy would directly conflict with the vertical envelopment concept, which assumed the ability to use C-130 aircraft to maneuver to operational depths, presumably well

¹⁵ UAMBL, “Change 1 to TRADOC Pamphlet 525-3-90 O&O,” November 25, 2002, p. 4-19.

¹⁶ UAMBL, “Change 2 to TRADOC Pamphlet 525-3-90 O&O,” June 30, 2003, p. 4-18; UAMBL, “Change 3 to TRADOC Pamphlet 525-3-90,” December 16, 2005, p. 4-9.

¹⁷ UAMBL, “Change 1 to TRADOC Pamphlet 525-3-90 O&O,” November 25, 2002, p. 4-19; UAMBL, “Change 2 to TRADOC Pamphlet 525-3-90 O&O,” June 30, 2003, p. 4-18; UAMBL, “Change 3 to TRADOC Pamphlet 525-3-90,” December 16, 2005, p. 4-9.

¹⁸ UAMBL, “Change 2 to TRADOC Pamphlet 525-3-90 O&O,” June 30, 2003.

within enemy territory. The underlying dilemma, which the FCS program apparently left largely unaddressed at the time that it adjusted concepts to fit requirements, was how changes in requirements intended to enable C-130 deployability affected the ability of the FCS SoS to fulfill the larger operational concept. The larger question was how these adjustments to the operational concept would affect the military utility of an FCS brigade, and whether that reduced utility would still justify the tremendous program costs.

Changes to Operational Requirements Were Allowed, but Trades and Requirements Relief Did Not Occur Often Enough

In any SDD program, requirements are expected to change as the program proceeds and discovers better ways of doing things, as well as when the program encounters problems that require specification changes to proceed further. This is especially true for a complex program like FCS where the need for flexibility in requirements is likely to be greater, given its ambitious goals. If the LSI or one of its subcontractors decided that a change to a requirement or engineering specification was beneficial or required, then that party prepared an Engineering Change Proposal (ECP). An ECP would define the technical nature of the change as well as its cost and schedule impact. The ECP would then be submitted to a series of change boards, depending on the tier in the LSI organization at which it was generated. Boards would review the ECP and either accept it, reject it, or ask for a resubmission that would respond to questions raised by the change board. As part of this process, ECPs could be rejected by representatives of the LSI or the Army, with the Army having the final say if there was a dispute, in accordance with the terms of the contract.

The Requirements Change Process Made Timely Trades and Change Approvals Difficult

According to a number of interviewees, the execution of the ECP process was flawed. It typically took between 6 and 18 months to process an ECP, that is, to be told if the program had accepted or rejected a proposed change.¹⁹ Interviewees provided a number of examples of the arduous ECP process. For instance, the 40mm ammunition specified for FCS could not be designed to satisfy the HEMP requirement, which mandated that the ammunition should function after being subjected to [the electromagnetic pulse emanating from] a high-altitude, thermonuclear explosion.²⁰ The HEMP requirement demanded ammunition that was beyond state-of-the-art technologies at that point. Regardless, former program officials described the onerous and lengthy process conducted to persuade the Army PM to exempt the 40mm ammunition from the

¹⁹ Interview with former program official, March 7, 2011.

²⁰ Interview with former program official, March 16, 2011.

HEMP requirement after the LSI had refused to provide an exemption.²¹ Similarly, as suggested elsewhere, the C-130 transportability requirement persisted until 2009, long after it was widely known throughout the program that the requirement could not be met. Apart from this high-level requirement, at one point the MGV program had generated some 147 ECPs, of which only 17 were approved.

TRADOC Representatives Were Typically Unwilling to Grant Requirements Relief

A widely cited success of the FCS program after it passed Milestone B was that TRADOC embedded official representatives throughout the LSI, its subcontractors, and Army Materiel Command facilities to help manage requirements trades and changes. Known as TRADOC Capabilities Managers (TCM) or TRADOC Systems Manager (TSM), these representatives were detailed as subject matter experts on-site at subcontractor facilities and at LSI headquarters. At the subcontractor level, their purpose was to provide “direct user input for fightability of each aspect of FCS, focused on man-machine interface questions.”²² At the LSI level, TSMs were responsible for providing the LSI “direct user input for commonality, FCS family member interactions, and supportability.”²³ Although these representatives would interact daily with engineers, they would not have any decision authority, and they were ordered to refer to UAMBL anything beyond providing input. To some degree, this facilitated the decomposition and translation of requirements into solutions, since engineers could go directly to on-site TRADOC representatives rather than to TRADOC with questions related to operational requirements.

But this evidently did not make it easier to relax or adjust requirements. Former program officials explained that there were many attempts to change requirements that could not be met. However, interviewees recalled that TRADOC personnel generally responded to such requests by retaining the requirement and asking the engineers to “work the problems harder.” The precise extent to which requirements officials actually rebuffed ECP requests, and the specific circumstances of such rejections, are impossible to establish in hindsight. Nevertheless, the frequency with which former FCS engineers and managers cited this attitude on the part of the user community suggests an important, underlying problem: a lack of trust and cooperation between the requirements and engineering communities that, though not specific to FCS, may have been particularly problematic considering the gap between ambitious requirements and more modest technological realities. As interviewees noted, resistance to granting requirements relief was common in TRADOC.²⁴ The attitude on the requirements committee, according

²¹ Interview with former program official, March 16, 2011.

²² Kevin P. Byrnes, “Future Combat Systems (FCS) Development Support Directive,” unpublished memo, U.S. Army TRADOC, July 19, 2003, p. 2.

²³ Byrnes, 2003, p. 2.

²⁴ Email correspondence with Army official, August 10, 2011.

to interviewees, was that granting requirements relief to engineers would lead to a slippery slope of cascading schedule delays and ultimately reduced capabilities.²⁵

While UAMBL Was Technically Empowered to Override Proponent Commands on Requirements Changes, Branches Exerted Significant Influence on Trades

Another issue was that Army proponents outside of UAMBL and TRADOC remained actively involved in managing requirements during the SDD phase. While UAMBL was charged with managing and integrating requirements, the proponent commands that originated the requirements “owned” them, in the sense that they originated and were regarded as expert authorities on those requirements; in many cases, proponent commands lobbied against relaxing their requirements when the LSI proposed requirements changes.²⁶ Active involvement of proponent commands was critical in the sense that they were able to contribute subject matter expertise to the continual refinement of requirements during the SDD phase. Proponent commands were valuable in the same way during the CTD phase. But since the Army’s schools and centers were stakeholders interested primarily in developing discrete systems and capabilities in their lanes of responsibility, and not the integrated system of systems, which crossed multiple lanes, they may have unintentionally undermined the brigade-level approach to requirements.

UAMBL ultimately had the authority to make changes to most requirements. While tradeoff decisions affecting KPPs and critical supporting ORD requirements were reserved for the commanding general of TRADOC, the director of UAMBL, rather than directors of centers and schools involved in FCS, had final authority to make all other requirements decisions.²⁷ Although proponent commands lacked official authority to enforce or block requirements decision, they nevertheless continued to have significant influence on the requirements process post–Milestone B. Part of the problem was structural: a two-star general led FCS, but generals of the same rank led the proponent branch commands that owned many of the FCS requirements, as well. Although UAMBL owned the ORD, the schools owned the individual requirements, meaning that UAMBL often lacked the expertise and knowledge to change ORD requirements without the consent of the schools.²⁸ When UAMBL or the LSI tried to move a requirement from the SoS to one vehicle or another, for instance, they would have to run that change through the school, first.²⁹ As one interviewee explained, all of the centers and schools “got a vote” on all requirements from the beginning of the program until the end. This created a significant obstacle to requirements flexibility throughout the program.

²⁵ Interview with former program official, September 22, 2010.

²⁶ Interview with former program official, August 10, 2011.

²⁷ Byrnes, 2003, p. 2.

²⁸ Interview with former program official, August 10, 2011.

²⁹ Interview with former program official, August 10, 2011.

Additionally, the TRADOC representatives detailed to subcontractors were technically answerable to UAMBL, but they were detailed from specific proponent commands rather than UAMBL itself. They were intended to play a supporting role to UAMBL. The Armor School, for instance, was singly responsible for providing support to the Mounted Combat System, Reconnaissance Vehicle, Armed Robotic Vehicle, and Command and Control Vehicle, while the Chemical School detailed representatives (technically on behalf of UAMBL) to subcontractors working on all nuclear, biological, and chemical-related FCS sensors and components.³⁰ In this sense, TRADOC representatives embedded at the system and subsystem levels were responsive to UAMBL in addition to, if only in a more informal sense, their own user communities, which gave individual branches significant influence over the requirement change process.

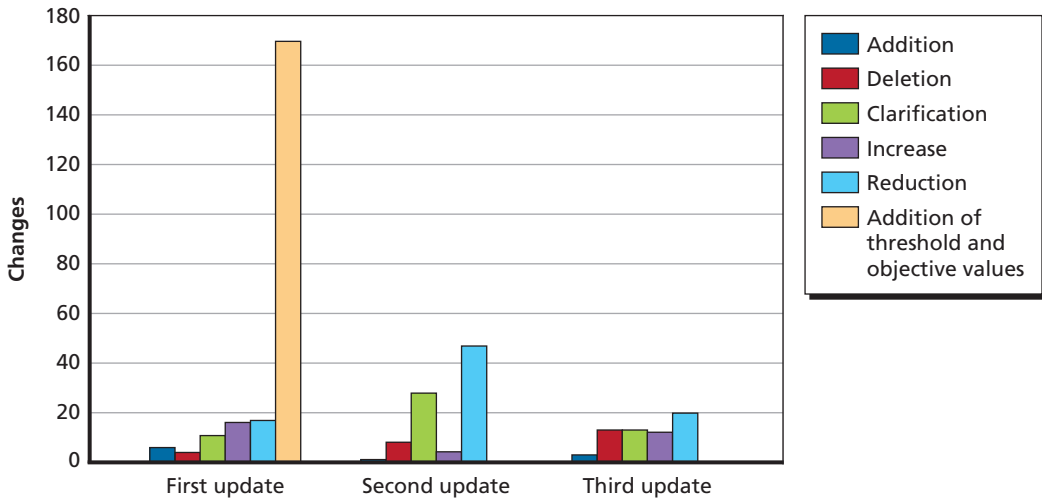
Almost Half of Changes to the ORD Consisted of Addition of Threshold Values to Requirements

In any SDD program, requirements are expected to change as the program proceeds and discovers better ways of doing things, as well as when the program encounters problems that require specification changes to proceed further. To determine how FCS requirements changed over time, we developed a database of all operational requirements from three official, JROC-approved versions of the ORD and the unofficial CDD that the program developed between 2007 and 2008 but never went before AROC or JROC for official approval (shown in Figures 5.1, 5.2, and 5.3). By tracing how each requirement evolved across multiple iterations, we were able to develop a picture of what types of requirements, classified both by system and by KPP category, changed as well as how they changed. We found that of 373 total, nonsuperficial changes to requirements across three official versions of the ORD and one unofficial version of the CDD (effectively a draft ORD that was never approved by JROC as a formal acquisition directive), by far the most changes were additions of threshold requirements to objective requirements in the second iteration of the ORD in 2005.

Of 560 ORD requirements that were initially written, 170 included only objective, nonbinding requirements, meaning that almost 30 percent of original ORD requirements that JROC approved established loose and aspirational rather than binding, minimal requirements. Additions of threshold values to ORD requirements written into the 2003 ORD with only objective values amounted to 46 percent of the total number of nonsuperficial changes captured by the ORDs and draft CDD between 2005 and 2008. Reductions of ORD requirements represented the second-highest percentage of changes to ORD requirements between 2003 and 2008. Of 373 total changes, 84 (23 percent) were reductions. Given the large number of unrealistically

³⁰ Byrnes, 2003, pp. 2–3.

Figure 5.1
Requirements Changes by Type from 2005 to 2008



SOURCE: UAMBL.

NOTE: Scale shows number of ORD requirements change in each version.

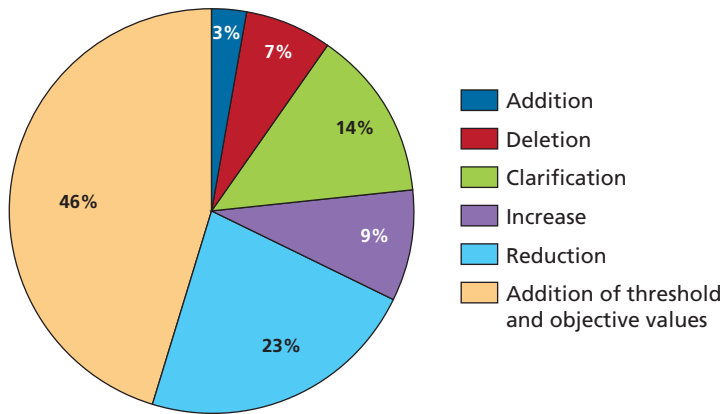
RAND MG1206-5.1

ambitious requirements, this makes sense, since program officials were forced to walk back many requirements as technical limits increasingly collided with early and optimistic (and in many cases unrealistic) expectations. That there were many more deletions of requirements than additions reinforces the same point. Figure 5.2 has the breakdown of changes by type for 2005–2008.

More than a third of requirements that were written into the 2003 ORD with only objective and no threshold values fell under KPP 2, agility and versatility, by far the largest percentage (Figure 5.3). Of 170 ORD requirements to which UAMBL added threshold values in the 2005 ORD, 58, or 35 percent, fell under that category. This class of capabilities dealt primarily with the battle command network and how it enabled situational awareness and understanding.

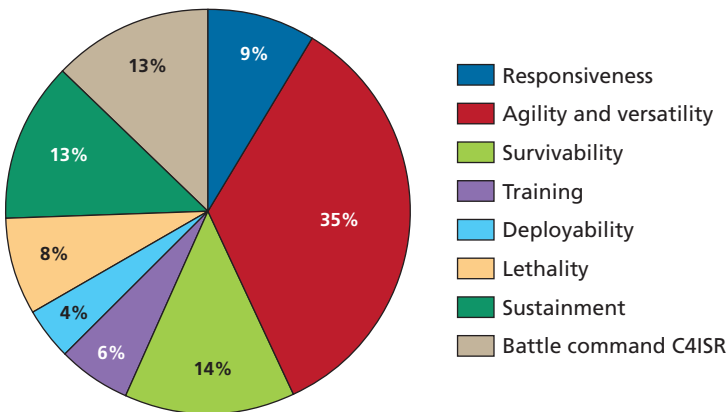
In many cases, thresholds were not set for these requirements because the network was insufficiently understood. In some ways this made sense, since it may have been counterproductive to feed developers threshold requirements that were poorly understood and may have been based on thin technical evidence. (That sense of caution did not seem to apply equally to transportability requirements, however.) As for reduced requirements, of 84 total ORD requirements reduced between 2003 and 2008, most (32 percent) fell under the agility and versatility KPP, suggesting again that these requirements were less well understood by requirements developers initially and therefore required more changes as engineers explored technical limits and solutions following Milestone B. The second largest number of reductions was to surviv-

Figure 5.2
Breakdown of ORD Changes by Type from 2005 to 2008



SOURCE: UAMBL.
 RAND MG1206-5.2

Figure 5.3
2003 ORD Requirements Without Thresholds and Objectives

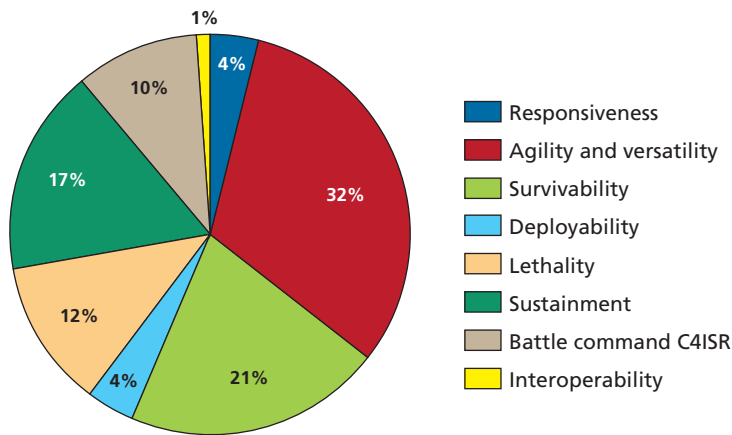


SOURCE: UAMBL.
 RAND MG1206-5.3

ability requirements (18 of 84 total reductions, or 21 percent), followed by sustainment requirements, 14 of which (or 17 percent of all reductions) were reduced between 2003 and 2008 (Figure 5.4).

The percentage of requirements that were either given threshold values in 2005 or reduced mirrors the overall breakdown of ORD changes from 2003 to 2008. Again, by far the most changes to requirements were made to those falling under the agility and versatility KPP. There were 117 changes to those requirements (31 percent of the

Figure 5.4
Breakdown of Types of ORD Requirements Reduced from 2003 to 2008



SOURCE: UAMBL.
 RAND MG1206-5.4

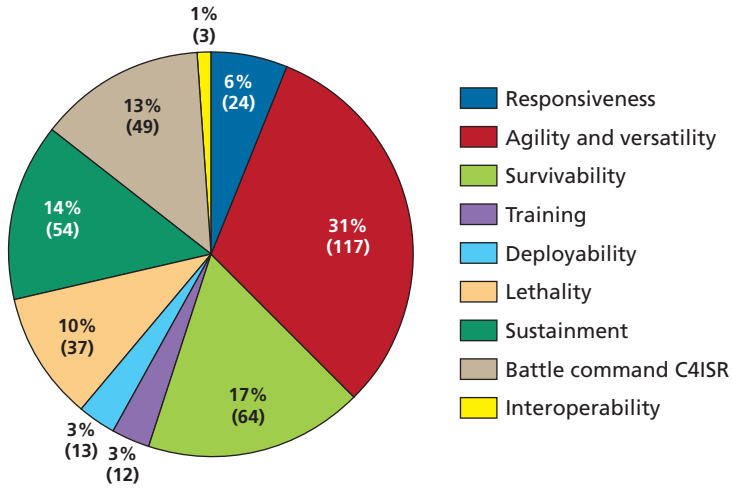
total number of 373 ORD changes), of which 58 percent were additions of threshold values in the second version of the ORD in 2005. Again, the second largest number of changes was made to survivability requirements (17 percent), and the third largest was to sustainment requirements (14 percent), as illustrated in Figure 5.5.

Figure 5.6 breaks down requirements changes by family of systems. The largest number of changes was made to the Manned Ground Vehicles, with the second, third, and fourth largest number of changes to Unmanned Ground Systems requirements, top-level Family of Systems requirements (encompassing all systems), and C4ISR requirements, respectively.

The large number of changes from 2003 to 2005 created significant instability in those requirements, since the lack of threshold values meant that TRADOC was given more time to adjust them as it developed a better understanding of how network technologies would actually work. Since some of those technologies (in the network as well as other domains) were relatively immature, many requirements were left as flexibly defined objectives rather than hard thresholds in order to allow those technologies to mature. Indeed, outside auditors later cited inadequately defined and unstable requirements as a significant problem during the early stages of the SDD phase.³¹ While this highlights the danger of leaving requirements too flexible during the SDD phase,

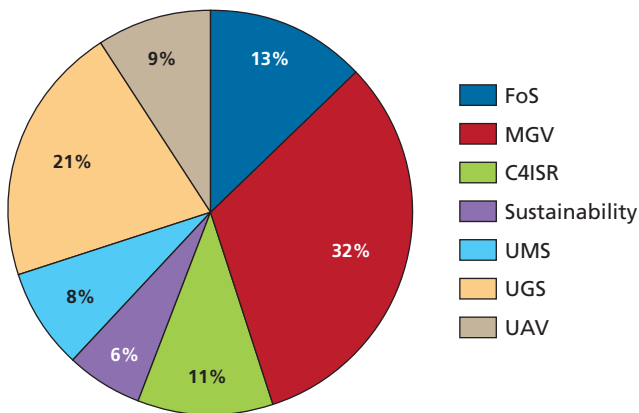
³¹ Paul L. Francis, "The Army's Future Combat Systems' Features, Risks, and Alternatives," Testimony before the Subcommittee on Tactical Air and Land Forces, Committee on Armed Services, House of Representatives, April 1, 2004; Paul L. Francis, "Future Combat Systems Challenges and Prospects for Success," Testimony before the Subcommittee on Tactical Air and Land Forces, Committee on Armed Services, House of Representatives, March 16, 2005.

Figure 5.5
Breakdown of Total ORD Requirements Changes by KPP Capability Category



SOURCE: UAMBL.
 RAND MG1206-5.5

Figure 5.6
Breakdown of Total ORD Requirements Changes by Family of Systems



SOURCE: UAMBL.
 RAND MG1206-5.6

which appears to contradict the problem represented by the C-130 constraint, which was too inflexible, the more fundamental problem seems to have been that many of these requirements were not sufficiently well understood, since many of the required technologies were either immature or nonexistent, as the program rushed to Milestone B. Insufficient analysis and technical understanding of requirements was, as many interviewees recalled, a significant problem. This also created significant instability in those requirements, since the lack of threshold values meant that TRADOC was given more time to adjust them as it developed a better understanding of how the network would work.

Sensor-to-Shooter Loop Slowed as Difficult Data Fusion Requirements Were Scaled Back

Improved survivability through enhanced situational awareness and understanding (SA/SU) in addition to precision strike capabilities formed a core tenet of the FCS concept beginning with the October 1999 Army Vision Statement. As the ORD explained, “The key enabler of the UA concept is the enhanced SA that leads to actionable SU.”³² That enhanced situational awareness and understanding could help substitute for heavy armor to increase the survivability of manned vehicles, and that advanced sensor, C4ISR, and network technologies could enable significantly improved SA/SU, form two of the core assumptions underpinning not only the FCS survivability but also the overall operational concept. The concept was encapsulated in what the Army referred to as the “quality of firsts”: see first, understand first, act first, and finish decisively. The idea was that achieving detailed and comprehensive (though not necessarily perfect) situational awareness and understanding of the adversary’s capabilities and intentions, FCS forces would be able to move to positions of advantage, shape the battlefield, and engage—and destroy or neutralize—enemy forces before the adversary had the ability to do the same.

The Layered Survivability Concept Was Dependent on Intelligence and SA/SU Technologies

By necessity, the concept placed a heavy emphasis on a rapid targeting cycle, from threat detection and identification to launching weapons at the target. The key enabler for rapid SA/SU acquisition, in turn, was rapid intelligence fusion, the process by which “data generated by multiple sources,” meaning the extensive array of battlefield sensors and intelligence collection platforms feeding the FCS SoS, “is correlated to

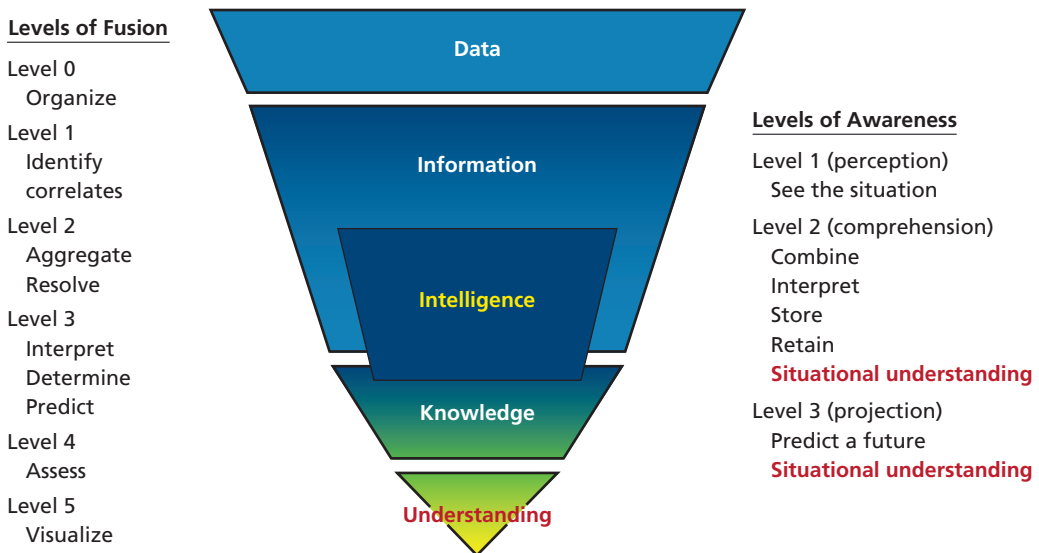
³² UAMBL, “Operational Requirements Document (ORD) for the Future Combat Systems,” January 31, 2005, p. 25.

create information and knowledge.”³³ While human cognition would be required, at least to some degree, to make final targeting decisions based on SA/SU, the concept placed a premium on automated fusion capabilities to accelerate the process and to make the human decision-making component of the cycle as minimal and easy as possible. The FCS program used five fusion levels that move through basic perception to understanding the threat and even projecting its future, illustrated in Figure 5.7.

Critical Intelligence Fusion Requirements Were Incrementally Scaled Back

Initially, the first version of the ORD mandated that FCS, as a threshold requirement, be able to perform Level 0 through Level 4 fusion, and up to Level 2 fusion in an automated fashion, such that it could “create, modify, and transmit a COP without a Soldier in the loop.”³⁴ This meant that the FCS C4ISR system would have to automatically generate, update, and broadcast throughout the FCS brigade a common operational picture (COP), a real-time, fused display of information on “terrain, weather, civilian, enemy, and friendly forces” intended to help the commander visualize the

Figure 5.7
Intelligence Fusion Model



SOURCE: UAMBL, ORD, January 31, 2005, p. A-4.

RAND MG1206-5.7

³³ UAMBL, “Operational Requirements Document (ORD) for the Future Combat Systems,” January 31, 2005, p. 25.

³⁴ UAMBL, “Operational Requirements Document (ORD) for the Future Combat Systems,” April 15, 2003.

battlespace and exercise command.³⁵ Level 2 fusion, according to the ORD, was the lowest level at which a COP could be generated.³⁶ Over the next several years, however, the threshold requirement was scaled back so that only 0–1 Level fusion was required, due to the fact that automated sensor fusion above Level 1 was judged not to be technically feasible.³⁷ This meant that the FCS battle command network could not generate a COP automatically, and that data from sensors would populate a database without being aggregated or deconflicted. Although this could result in actionable information, it would not have produced a COP or the intended level of SA/SU, thus degrading a key operational linchpin underpinning the FCS concept. As an FCS ORD gaps analysis explained, relaxing that requirement would also have necessitated a larger number of analysts to make sense of the sensor data, as well as expanded network bandwidth to deal with an increased flow of information.³⁸ As with the ambitious transportability requirements, data fusion requirements, though pivotal to the FCS operational concept, were premised on future, high-risk, and ultimately infeasible technologies.

Insufficient Network Bandwidth Also Limited Rates of Data Exchange and Restricted Survivability Concepts

Inadequate network bandwidth, which undercut data fusion requirements and compromised the quality of firsts, also illustrates this problem. The ambitious data fusion requirements underpinning the FCS concept placed massive demands on the network, but the network, as requirements developers gradually discovered, was unable to support the required level of bandwidth. In March 2007, the Program Manager for WIN-T, a critical technological enabler for the battle command network, explained that WIN-T would be “unable to fully support intelligence reach requirements until 2018.”³⁹ The result was to change a major assumption under which the FCS concept was developed, since the network would not be able to function as intended. The problem was partially the result of the fact that WIN-T, like JTRS, was a separate program, and FCS officials lacked the authority to manage it and resolve mismatches and variances between the programs in terms of technical requirements and schedule.

³⁵ UAMBL, “Operational Requirements Document (ORD) for the Future Combat Systems,” April 15, 2003, pp. J-1 to C-3.

³⁶ UAMBL, “Operational Requirements Document (ORD) for the Future Combat Systems,” April 15, 2003.

³⁷ UAMBL, “FCS Technology Gaps,” Excel spreadsheet, August 5, 2005.

³⁸ UAMBL, “Operational Requirements Document (ORD) for the Future Combat Systems,” January 31, 2005.

³⁹ U.S. Army Intelligence Center, “FCS Intelligence Summit Series: 2nd/3rd Quarter FY07,” unpublished briefing slides, June 19, 2007.

Requirements Did Not Adjust to Fit Operational Environment Changes

One of the most significant challenges that the FCS program faced was adapting to an evolving operational environment that undermined the assumption that lightweight armor could reliably protect soldiers in urban combat. The rise of the IED as the principal threat against U.S. soldiers in Iraq and Afghanistan led to a renewed emphasis on heavy armor as the most reliable way to minimize casualties. This and the failure of even the most sophisticated sensors, jammers, and other technologies to reliably protect soldiers from IED blasts directly challenged the FCS concept's reliance on tactical intelligence to compensate for heavy armor. Uncertain survivability against IEDs was ultimately one of the most important reasons for the cancellation of the MGV. As General Casey testified to the Senate Armed Services Committee in May 2009, the original design called for a flat-bottomed vehicle 18 inches off the ground, which "was clearly not survivable in this environment."⁴⁰ Since, as Casey explained, FCS was originally designed to fight conventional wars, the MGV became increasingly irrelevant the more Iraq and Afghanistan challenged the assumption that wars of the 21st century would be conventional.⁴¹

Later Versions of the System Threat Assessment Report Did Not Frame Insurgency and IEDs as First-Priority Threats

One of the foundational documents for the FCS program requirements was a System Threat Assessment Report (STAR), an intelligence assessment that TRADOC drafted and the DIA had to approve before it was incorporated into the formal program. The purpose of such an assessment is to describe the strategic and operational environment in which any new weapon platform will, once developed and fielded, be required to fight. DIA approved and validated several versions of the STAR: once several months before the program passed Milestone B, and then at two-year intervals thereafter.

The assessment is classified, so we do not describe it in any detail. But careful examination of all three versions of the STAR that were produced for FCS indicates at least one overarching, important, and of course unclassified finding. Although the assessment was updated to reflect the rising threat from insurgents and IEDs in operational theaters overseas, it did not present such threats as either highly probable or first-priority threats. Subsequent versions of the STAR did indeed draw increasing attention to IEDs and insurgent tactics, but it framed these unconventional threats as no more or less important or high-priority than other, conventional threats that the FCS design was optimized to dominate but which had become increasingly less relevant as the U.S. Army became entangled in counterinsurgency fights in Iraq and Afghanistan. This assessment may have reflected an astute judgment that—at least over the next

⁴⁰ Greg Grant, "FCS Not Killed: Casey," *DOD Buzz*, May 19, 2009.

⁴¹ Greg Grant, "FCS Not Killed: Casey," 2009.

25 to 50 years during which FCS forces would be expected to fight—conventional threats would probably remain just as important as unconventional threats after eventual extrication from Iraq and Afghanistan, but it conflicted with more immediate operational realities that senior U.S. officers and policymakers believed should have been vastly more important in terms of shaping requirements for a major, ongoing acquisition program.

Most Changes to Survivability Were Unrelated to the Increasingly Relevant IED Threat

Requirements, however, did not adjust in step with changes in the operational environment. Although armor and some standoff explosives detection and neutralization requirements ramped up as the IED threat increased, most changes in survivability requirements were unrelated to IEDs, and the most relevant modifications to the MGV design, a V-hull kit, came from outside the requirements community. As an October 2008 action memorandum notes, the request for this kit came directly from the CSA during an FCS survivability briefing the previous month.⁴² The ORD requirements themselves did not change to incorporate the mine-resistant hull. Moreover, by October 2008, IEDs had been killing U.S. soldiers for over five years in Iraq, and the Army had already ordered thousands of V-hulled MRAPs. To be sure, UAMBL modified the MGV survivability requirement for crew and passenger survival against the blast effects of mines, IEDs, and booby-traps, identified as a “primary threat to the FCS,” beside or under the vehicle. These changes were classified, and are not assessed here.⁴³ Nevertheless, the fact that they changed indicates that the requirements adjusted appropriately, at least to some degree, to the new operational realities.

But the majority of unclassified changes to MGV survivability requirements in three ORDs between 2003 and 2006 related to protection from CBRN, Directed Energy Weapons, or adversary electromagnetic targeting capabilities, technologies far beyond the reach of low-tech adversaries in Iraq and Afghanistan.⁴⁴ Of the 19

⁴² U.S. Army, “Future Combat Systems (FCS) Manned Ground Vehicle (MGV) V-Shaped Hull,” unpublished action memorandum, Headquarters, Department of the Army, October 7, 2008.

⁴³ ORD Requirement 2871 reads:

All FCS Manned Systems must provide XX percent probability of crew and passenger survival without life-threatening incapacitation against the blast effects of a XX kg mine (AT) or explosive blast beside or under the entire length of the platform and sustain a XX kg mine (AP) or explosive blast and continue without complete loss of mobility. (Threshold) All FCS Manned Systems must provide XX percent probability of crew and passenger survival without life-threatening incapacitation against the blast effects of a XX kg mine (AT) or explosive blast including shape charges or explosively formed penetrators beside or under the entire length of the platform (See Annex I). (Objective).

UAMBL, “Operational Requirements Document (ORD) for the Future Combat Systems,” April 15, 2003.

⁴⁴ From 2003 to 2005, on an unclassified level, 7 of 30 MGV ORD survivability requirements changed (23 percent), and one was added. Between 2005 and 2006, a further 11 MGV ORD requirements changed (35 per-

unclassified changes to MGCV survivability requirements across three versions of the ORD between 2003 and 2006, only one related to the types of improvised weapons used against U.S. forces in-theater, including Molotov Cocktails and other incendiary devices. However, the capability designed to protect against such weapons was actually downgraded, after threshold and objective cut-offs were inserted into an existing ORD requirement lacking such specific requirements. The most likely low-tech adversary weapons, such as Molotov Cocktails, are included in the Objective but not the Threshold capabilities, meaning that protection against likely insurgent weapons identified in the Rationale was desirable but not critical. (The requirement remained the same in the final JROC-approved ORD in April 2006.⁴⁵)

Additionally, although an objective requirement in the ORD called for protection against shaped charges and explosively formed penetrators (EFPs), the decomposed specs for this particular requirement disappeared from the SoS Specifications between March and July 2005.⁴⁶ It was replaced by specs requiring protection against the “effects of explosive hazard threats,” but it is unclear why, at a time when EFPs were becoming an increasingly dangerous threat, it made sense to eliminate that particular spec and broaden its definition.

The Army Eventually Mandated V-Shaped Hulls for MGVs to Counter IEDs, but Bypassed the Requirements Process

One of the most important MGCV design modifications intended to counter IEDs was implemented in a way that largely bypassed the requirements community. After General Casey became Army Chief of Staff in April 2007 after multiple tours in Iraq, he

cent). Thus, between 2003 and 2006, in two separate official revisions to the FCS ORD, there were 18 changes to 30 ORD requirements pertaining to the survivability of all FCS Manned Ground Vehicles, and one additional requirement was added. Of these 19 modifications, over half (10) were related to protection from CBRN, Directed Energy Weapons, or adversary electromagnetic targeting capabilities, technologies far beyond the reach of low-tech adversaries in Iraq and Afghanistan.

⁴⁵ ORD Requirement 3814:

Each FCS Manned System must provide 360 degrees hemispherical protection of crew and passengers and retain full or degraded mode capability in all primary mission function areas against fire and/or associated collateral effect resulting from malfunction or from ballistic penetration (Threshold), purpose-design flame and thermobaric weapons, and field expedient flame incendiary and thermite devices (Objective), to include electrical fire, burning stowage, Petroleum, Oils, and Lubricants (POL) fires, and propellant fires. Rationale: Recent combat against low-tech adversaries, particularly in urban environments, has shown vulnerabilities of armored vehicles to flame devices such as Molotov Cocktails. Protection from such devices is necessary to conduct full spectrum operations.

UAMBL, “Operational Requirements Document (ORD) for the Future Combat Systems,” January 31, 2005.

⁴⁶ A March 2005 version of the SoSS, for instance, specifies that “Shaped Charge Mine Protection—Objective. All FCS Manned Systems shall protect against shaped charges and explosively formed penetrators specified in [R-386]. (ORD 2871)(SOS-37385).” Boeing Company, “System of Systems Incremental Specification for the Future Combat System, (Revision D),” prepared for Tank-automotive and Armaments Command (TACOM), U.S. Army, March 2, 2005, p. 105.

was reportedly dissatisfied with the level of ballistic protection that MGVs provided. He therefore directed the Army to initiate development of a “V-shaped kit,” an add-on armor package that could be bolted to the bottom of an MGV hull to improve blast and fragment protection against IEDs.⁴⁷ These kits reportedly added several tons of weight and were to be applied once MGVs were delivered to theater.⁴⁸ The addition of a V-hull, which was becoming standard on up-armored vehicles being hurriedly shipped to Iraq and Afghanistan, made sense. What is interesting, however, is that the request was delivered directly to engineers working on the common MGV chassis, rather than being formally integrated into program requirements.⁴⁹ Interviewees suggested that one reason for this tack was that UAMBL had not considered a V-hull solution before 2008 because their concept continued to rely on a layered approach to survivability and ballistic protection, in spite of increasingly clear limitations to the onion-like quality of firsts and limits to standard ballistic protection against powerful IED blasts.⁵⁰

Failure to Adjust to IED Threat Bespoke Inflexible Operational Concepts and Continued Reliance on Unrealistic Technology

It is unclear why exactly the MGV continued to be so vulnerable to IEDs when a requirement for “robust countermine capability” was present from the beginning, and the capacity to dominate asymmetric warfare was, at least officially, a core FCS concept.⁵¹ But there are several partial explanations. First, FCS requirements developers foresaw the IED threat but underestimated how significant it would be and how difficult it would be to protect against.⁵² Of course, this underestimation was not limited to the FCS program; few people in the military predicted how dominant a threat IEDs would become. Second, while early concepts had the correct insight that FCS forces would have to fight in asymmetric conflicts and defend against IEDs, that concept was so advanced that it was impossible to achieve.⁵³ Although FCS was not intended to have perfect intelligence, the quantity and quality of intelligence and unmanned Ground Vehicles (UGV) countermine capabilities that would have been required to protect thinly armored vehicles reliably against most IEDs would have been impossibly high. Third, requirements simply did not adjust sufficiently to keep pace with the threat. To some degree, this would have been impossible without overturning high-

⁴⁷ U.S. Army, “Future Combat Systems (FCS) Manned Ground Vehicle (MGV) V-Shaped Hull,” October 7, 2008.

⁴⁸ Paul McLeary, “FCS Makes Journos Sweat for Their Scoops,” *Aviation Week*, June 12, 2008.

⁴⁹ Interview with former program official, February 11, 2011.

⁵⁰ Interview with TRADOC official, August 31, 2011.

⁵¹ U.S. Army, “Draft Mission Needs Statement for Future Combat Vehicle (FCV) Capability,” 2000, p. 4.

⁵² Interview with TRADOC official, April 12, 2011.

⁵³ Interview with TRADOC official, April 12, 2011.

level requirements and key concepts, such as C-130 transportability, which would have required high-level intervention. The concept was so reliant on advanced C4ISR to provide survivability that it would have required fundamental revisions once unprecedented tactical intelligence could no longer be assumed as a technological possibility. While this occurred with the 2008 CDD, with the elimination of the C-130 requirements and the addition of force protection as a KPP, the CDD remained in draft form until the program's termination. As a result, the revised requirements never flowed down to design specs.

Conclusions and Lessons

Conclusions

As the FCS program approached the SDD phase, the United States military invaded Iraq and opened the door to a fundamental shift in the type of war that it would be expected to fight for at least the next decade. In Iraq and increasingly in Afghanistan, insurgency became the primary type of conflict and IEDs the primary threat. Changes in the operational environment were considered in the program. Parts of the STAR were rewritten, insurgency-like operational scenarios were added to the O&O Plan, and some requirements changed. But the altered threat landscape did not fundamentally alter formal requirements, largely because of static operational concepts and technology assumptions that were incompatible with emerging threats.⁵⁴

To some degree, this problem was beyond the program's control. While FCS rested on the expectation that conventional warfare would dominate the 21st century, 9/11 and the invasions of Afghanistan and Iraq quickly altered that assumption. A brigade intended primarily to fight conventional warfare cannot be redesigned simply or quickly to fight counterinsurgency. Requirements intended to enable dominance in one type of warfare cannot easily be rewritten to dominate another, and so in some ways, it is unfair to fault FCS for providing substandard survivability capabilities against IEDs when it was optimized for MCO.

Lessons

Some lessons from the preceding chapter on the generation of requirements would apply equally to the SDD phase.

Revalidating operational concepts periodically will ensure that the capability being acquired remains relevant. The Army's main assumption seems to have been that the qualities that would enable FCS to dominate MCO, such as tactical agility, maneuverability, precision lethality, and cutting-edge situational awareness, would apply equally to other than MCO warfare. The U.S. military's experience in Iraq

⁵⁴ Interview with former program official, February 2, 2011.

and Afghanistan disproved this assumption, demonstrating, most importantly, that no level of currently achievable tactical intelligence can substitute for physical force protection. But this realization was slow to set in, and the FCS operational concept remained static.

Any operational force optimized for one type of warfare will have relative strengths and weaknesses. While those strengths came across clearly in the O&O Plan, ORD, and other high-level requirements documents, the relative weaknesses of FCS were not articulated with equal clarity, even though they were equally important. In the future, such weaknesses should draw at least as much scrutiny and attention as a program's presumed strengths. If changes in the operational environment make those weaknesses increasingly important, or, as in the case of FCS, undermine core concepts and assumptions, programs should be flexible enough to adjust pertinent concepts and requirements appropriately.

Immature technologies and insufficient understanding of requirements can lead to instability and significant changes later. The history of the FCS program after Milestone B illustrates the importance of thorough technical understanding of requirements before transitioning to the SDD phase. Because requirements developers lacked solid technical understanding and analysis of many requirements, to a large degree because many of the technologies were underdeveloped and immature, they let those requirements remain flexible by not inserting threshold values in the first version of the ORD. But the lack of firm requirements created problems for engineers as they began developing design solutions for requirements that remained unsettled and continued to change more than two years after Milestone B.

Such a thin technical base of understanding should have signaled a need to delay engineering while experts continued to determine how exactly the network should operate and what could reasonably be expected. The immaturity of many required technologies should have prompted program officials to delay Milestone B several years as those technologies matured and as engineers' understanding of those technologies developed. This also suggests the need for a refined operational architecture to describe in greater detail how a system of systems would operate and how the network would enable component systems to achieve brigade-level functions.

Changes to requirements related to transportability and intelligence fusion also point to the problem of insufficient technical understanding and validation of requirements leading up to the SDD phase. The negative impact on the operational concept as those requirements were reduced also highlights the peril of premising revolutionary ways of fighting on high-risk, untested, and largely unknown technologies. Assumptions that those revolutionary technologies would evolve to achieve equally revolutionary concepts turned out not to be the most effective approach, particularly when the timeline was radically compressed. While revolutionary concepts and technologies are important to pursue, a more cautious approach might allow technologies to develop more deliberately, and then structure operational concepts around technically

more mature capabilities. The FCS program took the opposite approach, assuming that high-risk technologies would fill ambitious operational needs. Reliance on assumptions was a major weakness; when those assumptions gave way, so, too, did the operational concept. This argues again for the continuous reassessment and revalidation of the operational concept, in light of changing requirements and a continuously evolving conflict environment.

Over the course of the FCS program, the structure and content of the requirements moved closer to a true “integrated” set, which the Army has long sought to achieve. Many requirements and individual systems were aligned, scaled back, or eliminated, and engineers and combat developers increasingly worked together to understand how interconnected systems would work together, in addition to how their requirements should be written to foster interaction between component systems and to enable SoS-level capabilities. But the history of the FCS program after Milestone B suggests that significantly more work is needed to fully appreciate the difficulty of and best approaches to such a broad, complex undertaking.

FCS Program Management

This chapter describes the program management strategy and structure, and certain essential processes that the Army and its industry contractors adopted to manage the FCS effort. It focuses on those elements of program management that program staff identified as key drivers of the FCS approach to program execution. The chapter presents findings—based largely on the experiences of key program staff, and a critical look at official documentation available to the study team—on how the FCS program management approach was implemented in practice. As is the case with the other chapters, it ends with conclusions and lessons.

Program management addresses cost, schedule, technical, and risk management. It is a function of program strategy, the structure of the organizations that implement the strategy, and the practices (and processes) employed by those organizations. Technical tools and plans as well as various best practices that evolve with time support program management. In the end, however, program management is about human judgment. The FCS program had a unique and ambitious program management approach. Here, we describe key aspects of that approach as well as the Army's FCS program management experience, identifying both positive and negative aspects.

The research was conducted by reviewing select program documents to determine how Army planners envisioned FCS program execution. Cost, schedule, and performance data were derived from Selected Acquisition Reports (SARs) and other program documentation. Official program histories, organization charts supplied by the Army, and SARs were reviewed to understand the evolution of program management structures. Key government officials and industry personnel who participated in the program at various levels were interviewed along with outside experts. Through this largely qualitative research method, we sought to understand (1) the intent of program management structures and how program staff executed key program plans and processes, (2) their perception of the efficacy of those structures, plans, and processes, and (3) their adaptation, if any, of structures and key processes as the program environment evolved.

New Management Approaches and Tools Were Needed to Meet Program Complexity

As discussed in Chapter Two, program managers were challenged by the FCS schedule. At Milestone B in 2003, the Army's objective was to achieve IOC for the first FCS-equipped unit within 7.5 years, less than half the time that would have been typical for an acquisition of such vast scope.^{1,2,3}

Army officials responded to the complexity and scale of the FCS endeavor, and its compressed schedule, by developing a program management approach that had several notable attributes:

- an evolutionary acquisition strategy
- a system-of-systems management approach
- concurrent performance of program requirements development, design, and implementation
- fielding of complete FCS-equipped Unit of Action with initial capability by the end of the decade
- an Other Transaction Agreement (OTA) contract vehicle
- establishment of a "One Team" partnership between the government and industry
- implementation of an Advanced Collaborative Environment (ACE).

The evolutionary strategy adopted for FCS program execution was considered a "new approach" to acquisition, according to the first Program Manager of FCS (PM FCS), Brigadier General Donald F. Schenk.⁴ Incremental acquisition was separate from the later defined "spin-outs," which were installed in the program in 2004/2005. The increments were a way to limit both the breadth of technologies and the depth of meeting overall capabilities of each requirement. The breadth limitations were such that Increment 1 contained only a portion of the 18 original systems, leaving others for future increments. The depth was limited in that Increment 1 would meet threshold requirements as stated in the Operational Requirements Document. Increment 1 at

¹ Brigadier General Donald F. Schenk, FCS Program Manager; Colonel Daniel J. Bourgoine; and Bryan A. Smith, "Unit of Action and Future Combat Systems: An Overview," *Army AL&T*, January–February 2004, p. 3.

² The Army was pressured to show it was responding to the Bush Administration's call for defense-wide "transformation," and thus wanted to move out quickly with the FCS program, which was to be part of the Army's transformation at several levels. Lieutenant General Joseph Yakovac, USA (Ret.), *Early Lessons Learned from the Army's Future Combat System: Developing an Appropriate Contractual Arrangement with Industry, Establishing and Enabling Program Management Structure and Test Organization*, Monterey, Calif.: Naval Postgraduate School, September 30, 2007, p. 4.

³ The demanding schedule was dictated early in the program by then-CSA General Eric Shinseki. See General Eric K. Shinseki, Chief of Staff of the Army, and Gregory R. Dahlberg, Acting Secretary of the Army, "Charter: Objective Force Task Force," no date, p. 3.

⁴ Schenk, Bourgoine, and Smith, "Unit of Action," p. 6.

Milestone B would reach an IOC in 2010 (with a limited-size brigade) and then eventually field 15 BCTs equipped with some of the systems.⁵ FCS Increment 1 would be followed by additional increments in order to complete the FCS objective capability; however, the details of future increments (in terms of solidifying the overall requirements being met, or the systems that would be integrated) were not described early in the program and eventually became moot as the spin-outs took root, and schedule expanded.

The insertion of FCS technologies to the Units of Action would continue throughout each increment as high-payoff technologies matured and became ready for integration. The program referred to this process as “spiraling in technology.”⁶ The PM believed that producing and fielding systems as their technologies matured would enable the program to deliver capabilities to warfighters more rapidly than traditional acquisition approaches while at the same time mitigating cost and schedule risks.⁷

The FCS program’s compressed schedule compelled program managers to conduct FCS research, development, system engineering, testing, prototyping, and other key activities concurrently. Indeed, according to Schenk, the schedule required an “unprecedented level of concurrency where all stakeholders act in concert as one team.”⁸

Figure 6.1, contained in a briefing dated April 18, 2003, depicts the FCS program’s Integrated Program Summary for Increment 1 from Milestone B through the start of Full Rate Production. The engineering, design, test, and production activities have a high degree of concurrency. As shown in the figure, the program’s SoS preliminary design review (PDR) was scheduled for the end of calendar year 2004. Planners working at the outset of the program intended to take risks to meet ambitious schedule goals. For example, the SoS critical design review (CDR) was scheduled just 15 months after the SoS PDR, system engineering would be completed by PDR, and major system design work would be conducted after CDR. Finally, rate production initiation and IOC were scheduled before completion of the integration and test phase.⁹

Leaders Deemed “System-of-Systems” Approach Suitable

Well before the handoff from DARPA, Army leaders had decided that a system-of-systems management approach would be required to enable FCS program managers

⁵ Department of the Army, Program Manager, Future Combat Systems, *Acquisition Strategy Report Future Combat Systems*, D786-10160-1, May 13, 2003, p. 9.

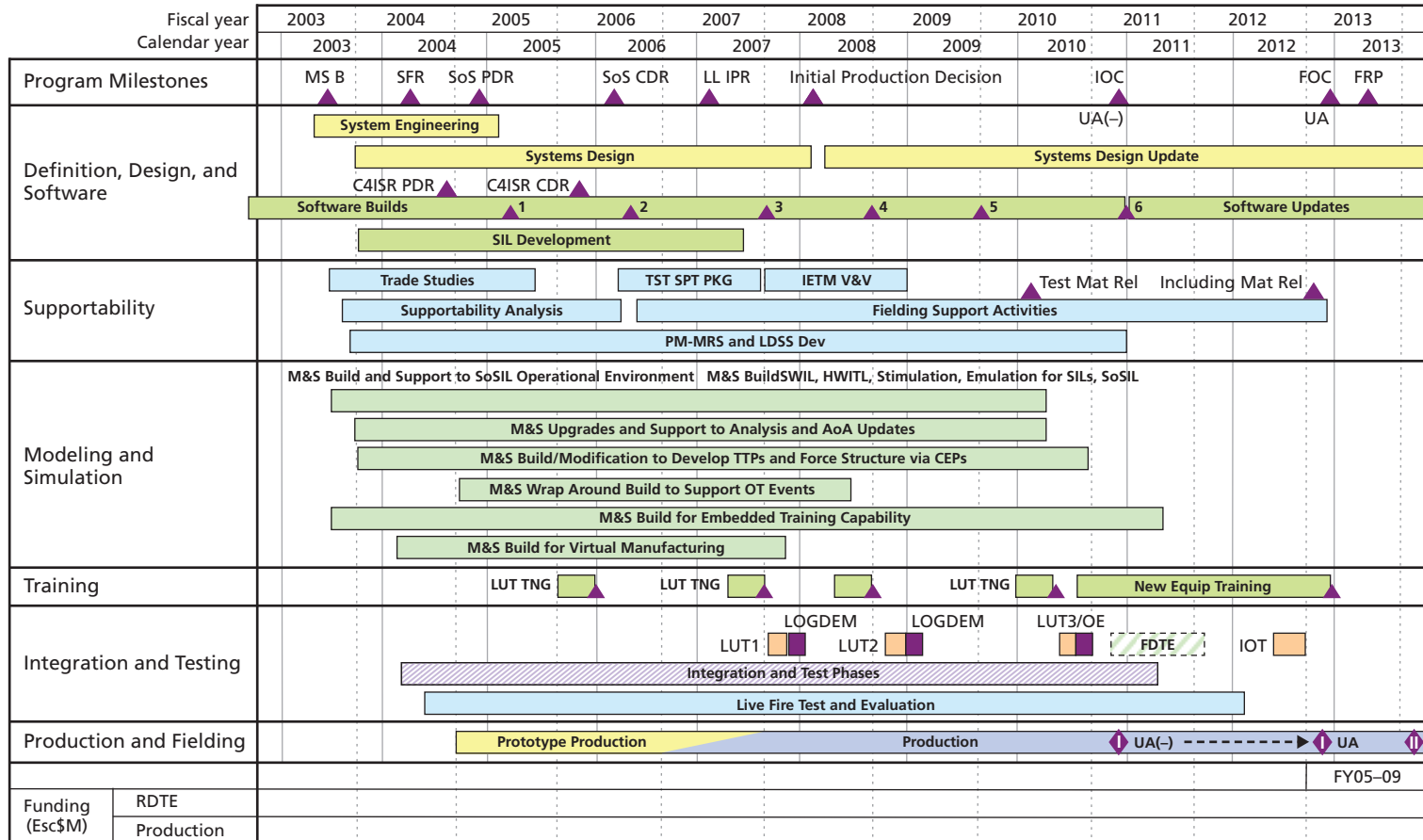
⁶ *Acquisition Strategy Report Future Combat Systems*, 2003, p. 21.

⁷ Schenk, Bourgoine, and Smith, “Unit of Action,” p. 6.

⁸ Schenk, Bourgoine, and Smith, “Unit of Action,” p. 3.

⁹ Brigadier General Donald F. Schenk, “Army Systems Acquisition Review Council Milestone B Decision Future Combat Systems,” slide presentation, Department of the Army, Program Executive Office Ground Combat Systems, April 18, 2003, slide 37.

Figure 6.1
Integrated Program Summary for FCS Increment 1



RAND MG1206-6.1

to integrate multiple technologies and systems to be deployed nearly simultaneously.¹⁰ Senior acquisition officials believed that the SoS approach was among the most unique FCS management features at the time.¹¹ But despite their development of innovative management techniques tailored to the FCS program and intended to accommodate its scope and complexity, senior program officials understood that FCS management and oversight would be very difficult.¹²

The Army Used an Other Transactions Agreement Contract at Start of the SDD Phase

The OTA was a continuation of DARPA's practice, and while OTA-type contracts had been used in the past, they had been used mostly for smaller prototyping efforts. According to the Army, the compressed schedule and complexity of the FCS program demanded the use of the OTA, which permitted innovative, streamlined business arrangements and nonconventional practices, flexible teaming, and government-industry collaboration.¹³ Army contracting officers described the OTA's use for SDD as a bold move.¹⁴ They asserted that the OTA vehicle provided for program management flexibility that was "unachievable" using more traditional procurement contracts.¹⁵ (Note: The contracting arrangements are more fully addressed elsewhere in this report.)

The "One Team" Philosophy Was Important to How FCS Developed Its Management Style and Structure

The FCS program adopted the One Team approach to promote intense government-industry collaboration, which Army officials thought was required to meet the FCS schedule. Army acquisition leaders envisioned a government-industry "team" years before FCS reached the SDD phase; the team concept was carried on through the program's entire life.¹⁶ Army contracting officers referred to an "industry- and government-shared destiny."¹⁷ Other Army officials set as a program objective the creation of "a solid enduring partnership between Combat Developers, Material Developers

¹⁰ Lieutenant General John M. Riggs, Director, Objective Force Task Force, "Objective Force Task Force RRC FCS Acquisition Management," briefing slides, September 5, 2001, slide 2R.

¹¹ Yakovac, *Early Lessons*, 2007, p. 9.

¹² Schenk, "Army Systems Acquisition Review Council," 2003, slide 40.

¹³ *Acquisition Strategy Report Future Combat Systems*, 2003, p. 16; and Pamela Demeulenaere, FCS Grants Officer, and Ignacio Cardenas, FCS Director of Acquisition, "FCS Lead Systems Integrator Contract," *Army AL&T*, January–February 2004, pp. 25–26.

¹⁴ Demeulenaere and Cardenas, "FCS Lead Systems Integrator Contract," 2004, p. 26.

¹⁵ Demeulenaere and Cardenas, "FCS Lead Systems Integrator Contract," 2004, p. 26.

¹⁶ Riggs, "Objective Force Task Force RRC FCS Acquisition Management," slide 2R.

¹⁷ Demeulenaere and Cardenas, "FCS Lead Systems Integrator Contract," 2004, p. 27.

and Industry.”¹⁸ TRADOC and Defense Contracting Management Agency (DCMA) officials called the FCS program management strategy “nothing less than a revolutionary change in the relationship between the Army and its private sector industrial partners.”¹⁹

Although seemingly at odds with the One Team approach, a high-risk attribute of the FCS program was its reliance on so-called complementary systems.²⁰ These systems were to be developed, or were already under development, outside of the FCS program. The FCS team did not control complementary systems, but the team was nonetheless tied to them. FCS’s successful integration with a number of complementary systems was understood to be vital to the achievement of FCS performance objectives. As one senior program official put it, complementary systems were the “glue that holds the FCS-equipped UA together.”²¹ Accomplishing effective interfacing with complementary systems was understood to be a major challenge by FCS leaders early in the program’s SDD phase.

FCS Established an Advanced Collaborative Environment

The ACE would host program documents, simulations,²² scenarios, and virtual prototypes. It provided a single access point for program management data on risk, schedule, and technical performance. It was intended to provide up-to-date information on all aspects of program health. The ACE would provide a capability for real-time collaboration within and between the Army, OSD, contractors, and other FCS program participants.²³ The ACE was therefore an essential tool for achieving the program’s One Team approach.

In sum, the Army used this vehicle to support the unique FCS program. The program had inherent, serious risks, such as the reliance on complementary programs that FCS managers did not control. The Army’s approach would demand unprecedented collaboration with defense industry to implement. Finally, FCS officials understood early on that they were attempting to implement a new paradigm in Army program management. Their success would hinge in large measure on senior program leaders’

¹⁸ Gary Tucker, “OTA, Award Fee, T&C’s: A Business Framework for System Design and Development,” briefing, January 6, 2003, slide 8.

¹⁹ Colonel Daniel J. Bourgoine, Matthew C. Danter, John Morroco, and Brian A. Smith, “The FCS One-Team Approach—The Linchpin for Program Management Success,” *Army AL&T*, January–February 2004, p. 9.

²⁰ Yakovac, *Early Lessons*, 2007, p. 9.

²¹ Colonel John R. Bartley, “FCS-Equipped Unit of Action Complementary and Associate Programs,” *Army AL&T*, January–February 2004, p. 22.

²² Hosting simulations was aspirational, but with few examples evident during our study. Other systems, such as a Cross-Command Collaboration Effort (3CE) discussed later on, had similar goals in mind.

²³ *Acquisition Strategy Report Future Combat Systems*, 2003, p. 17.

ability to enforce SoS discipline. Managers of FCS components had to be convinced that the SoS was the program's ultimate goal and, thus, their top priority.²⁴

Lead Systems Integrator Managed FCS Complexity, but Posed Other Challenges

The reduction in the Department of Defense budget after the Cold War resulted in a major shortfall of personnel in acquisitions and contracting career fields. With the digital revolution in technology and networks, the government sought to develop the next generation of war-fighting assets, which would rely on digital networks to integrate physical assets in a system of systems. These contracts would require significantly more manpower than was available to government agencies to manage the acquisition process. The government decided to follow a radical acquisition concept relying on a Lead Systems Integrator (LSI). In most cases, the LSI was a private contractor such as Boeing or Lockheed Martin or a consortium of private contractors. The LSI was tasked with building a team of contractors to build the SoS to meet government-designated capabilities. This differs from traditional acquisitions where the government would define specific requirements for the assets. The LSI is given the latitude to determine the best asset mix to meet the capability requirements.

To accomplish the goal of fielding initial FCS technologies by 2010, the Army decided to use a limited-LSI utilizing a spiral technology fielding process. The Army felt it was incapable of designing and developing the 18+ necessary systems along with the central network to field the FCS in half the time normally allotted for a single acquisition system.²⁵ The Army estimated it would require, just in 2005, thousands of additional scientists and engineers to fill vacant and new positions to support the program. In addition, it estimated that 12–24 months would be required to fully man, if possible, the Project Managing Office (PMO). The first milestone was set for 16 months after the project contract, making the government nearly incapable of achieving its goal on its own. At the time, the government could not predict the manpower drain, which occurred as a result of Operations Iraqi Freedom and Enduring Freedom. Using the LSI with civilian employees also made the acquisitions process “war proof” in the sense that the contracting officers were neither military nor likely to deploy in

²⁴ Akbar Khan, Program Manager, FCS CECOM Software Engineering Center, “Evolutionary Acquisition of Future Combat Systems (FCS),” slide presentation to the Software Acquisition Conference, January 27, 2004, slides 21 and 23.

²⁵ Scott Flood and Paul Richard, “An Assessment of the Lead Systems Integrator Concept as Applied to the Future Combat System,” *Defense Acquisition Review Journal*, December 2005–March 2006.

support of the war.²⁶ Thus, the Army needed an LSI in order to meet the ambitious schedule deadline.²⁷

The Army identified three primary advantages of using the Boeing/SAIC limited LSI: access to larger pools of talent in industry, the ability to hire talent much more rapidly and efficiently, as well as the ability to award and manage multiple large technical support contracts.²⁸ Of the options available to the Army for developing the FCS in such a short period, the Boeing/SAIC contract as an LSI provided was assessed as the best value for the FCS.²⁹ In addition, the Army prohibited the LSI parent organization (Boeing) from competing for any subcontracts beyond the system integration technology (System of Systems Common Operating Environment) in order to prevent conflicts of interest in second-tier competition by the LSI.³⁰ A GAO review of the program just before it was cancelled concluded that while the program was likely too complex and risky based on the capabilities it desired, it was a well-founded attempt to deliberately develop a common network to integrate the systems and the concept should not be abandoned.³¹ To be clear, a theme found throughout this study was that the Army's intent for creating FCS was correct, but the execution was riddled with far too many challenges.

Critics of LSI Use Cited Governmental Erosion of Acquisition Capabilities, Difficulty in Oversight, and Lack of Cost Control Measures

Unlike traditional acquisition contracts under the FAR, the FCS was originally contracted under OTA before being converted to a FAR contract in 2005. This provided government flexibility in assigning the contract, but was designed for companies that did not have the reporting capabilities of traditional defense contractors like Boeing and SAIC. By initially using the OTA, costly oversight processes were used by Congress and the DoD, driving costs up.³²

²⁶ Flood and Richard, 2006.

²⁷ Flood and Richard, 2006.

²⁸ Flood and Richard, 2006.

²⁹ Military Professional Resources Inc. (MPRI) performed a Return on Investment (ROI) analysis using its Program Management Best Practice (PMBP) architecture. It estimated the LSI contract would yield a significant ROI.

³⁰ Government Accountability Office, *Defense Acquisitions: Role of Lead Systems Integrator on Future Combat Systems Program Poses Oversight Challenges*, Washington, D.C.: Government Accountability Office, GAO-07-380, June 2007.

³¹ Paul L. Francis, United States Government Accountability Office, "Defense Acquisitions: Issues to Be Considered for Army's Modernization of Combat Systems," Testimony Before the Subcommittee on Airland, Committee on Armed Services, U.S. Senate, GAO-09-793T, June 16, 2009.

³² Andrew Feickert, *The Army's Future Combat Systems (FCS): Background and Issues for Congress*, Washington, D.C.: Congressional Research Service, RL32888, April 28, 2005.

The Institute for Defense Analyses (IDA) report in 2004 on the FCS, requested by the Army and the DoD, found that Boeing was performing within standards and that a time and savings cost may be realized with the OTA contract. Most of the IDA recommendations for improvement, including building a sound business case as well as reviewing contract clauses dealing with dispute resolution, cost accounting, and auditing, were addressed before the report was released.³³

A December 2005 study in the *Defense Acquisition Review Journal* noted that the major difficulties in the FCS program, to that point, were in the organizational culture. Industry and Army personnel felt the top leadership in the Army did not support the LSI approach to the FCS program, nor did they expound on the requirements to implement the LSI contract in the acquisitions offices. The LSI was not at fault for the initial organizational issues for which the Army did not prepare when developing the SoS conceptually. Government agents cited that the LSI was pandering to its own interests rather than the government's interests as desired, though that would be not unexpected from a private entity.³⁴ The GAO cited that it was unreasonable for the Army to expect a private entity to act in the best interest of the government if doing so conflicted with its corporate interests.³⁵

The LSI concept supposedly allows it to perform the subcontracting free from government contracting standards (though not the case with the FCS). However, evidence suggests the LSI was giving performance requirements below the government requirements contracted to the LSI.³⁶ The prototypes were not fully developed and tested by contract cancellation, so a full evaluation of the product quality from the subcontractors is not available. Another issue between the LSI and its subcontractors is the control of basic information required to execute the contract. The LSI controls data it perceives to be proprietary, with information otherwise provided to the subcontractor if directly contracted with the government. Whether this is a specific problem of using an LSI or if it requires more discrete contract language is difficult to assess. It requires more review to determine whether the contract is at fault or the LSI.³⁷

Another cultural tension with using the LSI is the relationship with its subcontractors. Many, especially in this case, competed directly with the LSI for the LSI contract and viewed the LSI as a competitor. Several complaints and accusations include not receiving a fair share of the contract, the LSI acting as a gatekeeper, and concerns by the LSI that its subcontractors might try to sabotage the LSI concept in Congress in order to attain individual contracts for each subsystem. A major information concern

³³ Feickert, 2005.

³⁴ Flood and Richard, 2006.

³⁵ Francis, "Defense Acquisitions: Issues to Be Considered for Army's Modernization of Combat Systems," 2009.

³⁶ Francis, "Defense Acquisitions: Issues to Be Considered for Army's Modernization of Combat Systems," 2009.

³⁷ Flood and Richard, 2006.

lies in the LSI's ability to oversee competitor proprietary data. Most of the remaining requirements and issues of using the LSI, such as vague contracting language, were not related to the use of an LSI but rather to the contracting methods used by the Army, which cannot be used to fault the LSI.³⁸

A 2007 GAO report on the role of the FCS LSI investigated the effectiveness of the contract. Many of the public issues with the FCS program revolved around inadequate contracting measures taken by the Army in assigning the LSI contract. These involved incentive fees that did not effectively incentivize expected progress and the shifting of project risk from the LSI to the government by guaranteeing payment regardless of product success. (These contracting issues are addressed in a separate chapter.)

In the same report, the GAO commends the Army's management of lower-tier contractors in comparison to traditional FAR-type contracts. In a traditional contract, the Army would contract the prime, which would then bring its own supply teams into the acquisition. The Army chose to maintain veto power over the second-tier contractors in the LSI acquisition process, with oversight on the third-tier subcontractors as well. This method helped maintain competition as well as government oversight lower in the supply chain, which helped to alleviate some oversight concerns in the initial contract.³⁹

In its use of an LSI, the government raised many questions pertaining to future competition and flexibility as it moved into production. While the program was significantly restructured prior to the start of low-rate production, the concerns are worth considering. The LSI was originally contracted to begin initial production in 2008 of Increment 1, with the expectation that future increments would follow. By taking this route, the Army made the LSI rather indispensable to the FCS program, and concerns were voiced about the limited role of the LSI.⁴⁰

LSI Structure Permitted Beneficial Government Role in Vendor Source Selection

The LSI proved adept at rapidly competing and executing subcontracts for major SoS components, and the program achieved a diverse supply base.⁴¹ Moreover, the government's co-leadership of IPTs enabled it to play a substantial role in the selection of subcontractors for the FCS program, and the Army could veto LSI source selections. The government's visibility into lower tiers of the LSI structure also enabled it to promote competition among lower-level suppliers and "ensure commonality of key subsystems

³⁸ Flood and Richard, 2006.

³⁹ Government Accountability Office, *Defense Acquisitions: Role of Lead Systems Integrator*, 2007.

⁴⁰ Government Accountability Office, *Defense Acquisitions: Role of Lead Systems Integrator*, 2007.

⁴¹ Although the LSI was, at the Army's direction, successful at rapid subcontracting, this activity ultimately damaged the program because, as detailed below, it resulted in some product building before preparatory systems engineering had been completed.

across FCS platforms,” the GAO determined.⁴² Such commonality promised to lower vehicle sustainment and life cycle costs.

LSI Generally Met Expectations

Major points for adjudicating success of the government/LSI relationships were not reached prior to cancellation, such as the critical design review. Over the years since Milestone B, program officials came to see that the relationship with LSI lay within contract standards. The LSI provided the expected services and technology developments as stated in the contract. The budget and schedule changes over time were largely a result of Army and government decisions, and the Army contract was likely too ambitious in its scope for both the budget and timeline.

IPT Structures Were Used to Assist with FCS Integration, One of the Program’s Biggest Challenges

The FCS program’s SoS approach, One Team philosophy, and need to conduct key program activities concurrently were among the factors that contributed to the Army’s decision to transition the LSI construct from the program’s CTD phase to the SDD phase. The Army would lead overall program management while the LSI contractor focused on SoS integration.

FCS program officials believed that they would have to “leverage the best available research and move [the program] forward” in partnership with industry’s technological leaders in order to meet the program’s schedule goals.⁴³ The LSI would serve as the government’s vital link to the industry community and was tasked with bringing the best of industry to the program.⁴⁴ In this vein, the structures of the LSI and government played vital roles in how they interacted and progressed throughout the FCS program.

As indicated in Figure 6.2, the government-industry “partnership” envisioned by Army acquisition experts was implemented by means of joint government-LSI participation in product- and process-oriented Integrated Product Teams (IPT). The program had a single Level I IPT for overall program management (called the PM IPT) and employed 14 Level II IPTs.⁴⁵ TRADOC assigned subject matter experts from through-

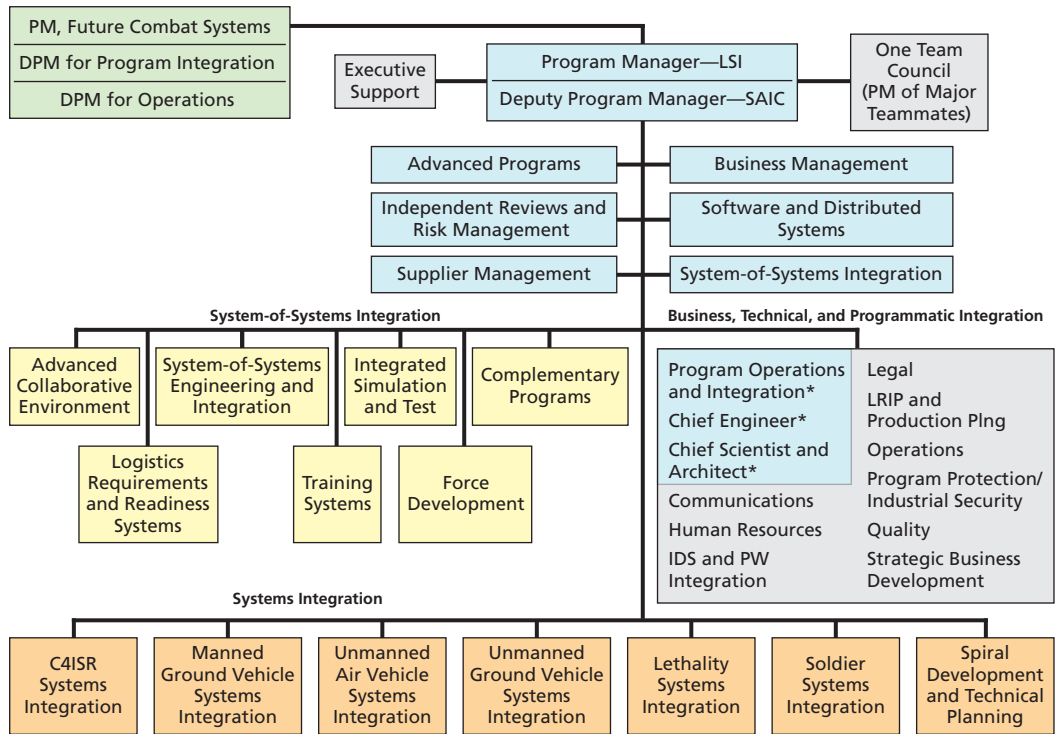
⁴² Francis, “Defense Acquisitions: Issues to Be Considered for Army’s Modernization of Combat Systems,” 2009, p. 3.

⁴³ Demeulenaere and Cardenas, “FCS Lead Systems Integrator Contract,” 2004, p. 27.

⁴⁴ Khan, “Evolutionary Acquisition,” 2004, slide 17.

⁴⁵ The 14 Level II IPTs included the following: Advanced Collaborative Environment; Complementary Programs; Force Development; Integrated Simulation and Test; Logistics Requirements and Readiness Systems; SoS Engineering and Integration; Training Systems; Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance Systems Integration; Spiral Development and Technical Planning;

Figure 6.2
Fiscal Year 2003 FCS SDD LSI Organization—Government Roles



* = Office of the Program Manager.

SOURCE: Program Executive Office Ground Combat Systems, FY03 Historical Report, p. 6.

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out its command to serve on each of the 14 Level II IPTs.⁴⁶ OSD maintained project “oversight” at the SoS level and achieved “insight to the program” through its participation in the Integrated Product and Process Development process.⁴⁷

In principle, a key advantage of the IPT approach was its ability to facilitate communications up and down the LSI structure.⁴⁸ According to the Army FCS project’s first director of engineering, Scott Davis, the IPT concept would help “ensure that

Lethality Systems Integration; Manned Ground Vehicle Systems Integration; Unmanned Aerial Vehicle Systems Integration; Unmanned Ground Vehicle Systems Integration; and Soldier Systems Integration. Schenk, “Unit of Action,” pp. 8–9.

⁴⁶ Schenk, Bourgoine, and Smith, “Unit of Action,” p. 10.

⁴⁷ U.S. Army, Department of the Army, Program Executive Office Ground Combat Systems, *FY03 Historical Report PM Future Combat Systems*, no date, p. 13.

⁴⁸ Department of the Army, Program Manager, Future Combat Systems, *Acquisition Strategy Report Future Combat Systems*, D786-10160-1, August 3, 2005, p. 49.

all stake holders have continuous input to the design, development, and integration process.”⁴⁹

FCS Integration Was Extraordinarily Challenging

As indicated in Figure 6.2, integration functions were undertaken at multiple levels within the structure. The SoS Integration group, shown to the left of the figure, had “authority to re-balance requirements and performance across system segment teams” (i.e., the C4ISR Systems’ Integration team IPT, the Manned Ground Vehicle Systems’ Integration team IPT, etc.).

In accordance with the OTA contract, the Boeing Company or SAIC led each IPT, and government officials served as co-leads. Decisionmaking would, ideally, result from industry-government consensus. If such consensus could not be reached, the OTA vehicle stated that decisions made by the LSI IPT lead would stand until the issue could be fully resolved. Government IPT officials could appeal to higher-level IPTs to overturn LSI decisions, and the Army’s PM had the final say in all disputes that reached PM level for resolution. However, the OTA also made it clear that “issue resolution by elevation to next higher level IPT is not the preferred method.”⁵⁰ Indeed, according to the Army, a “guiding principle” for FCS management was to “drive decision authority to the lowest practical level.”⁵¹ This principle was designed to prevent higher-level IPT decision makers from being overwhelmed by issues escalated from lower levels in the LSI structure.⁵²

Army acquisition leaders believed the LSI would work on the government’s behalf to bring the best of industry to the program, rapidly execute subcontracts for hardware and software development, and then make unbiased assessments of materiel solutions offered by the participating One Team subcontractors, some of which are listed in Table 6.1 along with their work scope. By 2005, the FCS program’s One Team included an industrial base comprising more than 350 contractors.⁵³

A key tenet of the FCS program was to “maintain and shape [the] government acquisition community.” Statements by program officials indicate that the Army acquisition community hoped to increase its own capacity for complex systems acquisition

⁴⁹ Scott Davis and Tom Bagwell, “System-of-Systems Integration: The Most Ambitious Army Program Ever,” *Army AL&T*, January–February 2004, p. 17.

⁵⁰ U.S. Army Tank-automotive and Armaments Command and the Boeing Company, “Agreement Between the Boeing Company and U.S. Army Tank-automotive and Armaments Command Concerning Future Combat System Development and Demonstration (SDD) Phase,” Agreement No. DAAE07-03-9-F001, May 30, 2003, p. 26.

⁵¹ *Acquisition Strategy Report Future Combat Systems*, 2003, p. 42.

⁵² Interview data.

⁵³ U.S. Army, Department of the Army, Program Executive Office Ground Combat Systems, *PM, UA Historical Report FY 2005*, no date, p. 5.

Table 6.1
FCS System Development and Design Team

Contractor	Work Scope
Boeing-SAIC	Lead Systems Integrators
BAE Systems	Armed Robotic Vehicle, Manned Ground Vehicles, Air & Ground Communication Integration
General Dynamics	Manned Ground Vehicles, Autonomous Navigation System, Sensor Data Management, Integrated Computer System
iROBOT	Small Unmanned Ground Vehicle
Lockheed Martin	Centralized Controller, Armed Robotic Vehicle, Multifunctional Utility/Logistics & Equipment Vehicles, Non Line of Sight Launch System, Training Instrumentation Architecture
Northrup Grumman	Class IV Unmanned Aerial Vehicle, Logistics Decision Support System, Network Management System
Honeywell International Inc	Class I Unmanned Aerial Vehicle, Soldier Mission Readiness System
Textron Systems	Unattended Ground Sensors and Tactical and Urban Ground Sensors
Raytheon	Ground Sensor Integration, Non Line of Sight Launch System, Battle Command & Mission Execution
Computer Sciences Corporation	Training Support Package
Dynamics Research Corporation	Training Support Package
IBM	Logistics Data Management System
Overwatch Systems	Situational Understanding

SOURCE: U.S. Department of Defense, Office of the Department of Defense Inspector General, Contracted Advisory and Assistance Services for the U.S. Army Future Combat Systems, Report No. D-2010-024, as redacted, November 24, 2009, p. 8.

through the LSI engagement over time. Indeed, DARPA's FCS program manager, Colonel W. R. Johnson, said in 2002: "We are not looking to just transform our tactical forces but the way we conduct acquisition."⁵⁴

In addition to IPTs, FCS employed specialized working groups or teams to focus on specific aspects of the program; the most important groups were: senior integration management team; requirements working group; trade study working groups; interface control working group; system integration working group; and the non-advocate review groups.⁵⁵ As indicated in Figure 6.2, the program management structure also included a "One Team Council." The council and its subteams were created to develop program strategies, approaches, and processes. Subteams developed affordability plans, the Earned Value Management (EVM) reporting system, program metrics and reporting processes, and the "management reserve/estimate-at-complete process implementation."⁵⁶ According to TRADOC and DCMA officials, the council met "regularly to integrate major

⁵⁴ Johnson remarks in preface, DARPA LSI Solicitation, circa January 2002, p. ii.

⁵⁵ Davis and Bagwell, "System-of-Systems Integration," p. 18.

⁵⁶ Demeulenaere and Cardenas, "FCS Lead Systems Integrator Contract," 2004, p. 27.

FCS SoS elements.” Its goal was “to standardize processes and share best practices, as well as set goals and schedules for moving ahead with the program’s SDD phase.”⁵⁷

Within the LSI structure, management of interfacing activities fell to a Complementary Programs IPT. This IPT was established to (1) identify outside programs that required interfacing, (2) develop an overarching integration and management approach, and (3) assist the government in the establishment of a memorandum of agreement (MOA) or other instruments designed to align the outside programs’ cost, schedule, and performance with FCS.⁵⁸ In general, the bulk of the actual work defining the interfaces fell to the integration and design IPTs.

IPTs with Essential Integration Responsibilities Across SoS Lacked Requisite Authorities

While several government co-leads serving on IPTs believed that program culture and policies suppressed their ability to exercise their fiduciary responsibilities for oversight, other critiques of the LSI structure concerned the authorities of specific IPTs that had cross-cutting responsibilities. In this regard, the Unit of Action SoS Integration organization needed more authority early on in the program to produce an integrated design and make “enforceable design trades” within the SoS.⁵⁹

Some former program officials had difficulty determining why even upper-tier SoS integration IPTs seemingly lacked the authority they needed to rebalance requirements and performance across system segment teams operating at lower tiers. They opined that the Army PM simply failed to instill in his line managers the notion that the FCS SoS was the program’s primary objective, and not the individual components that the managers oversaw.⁶⁰ As noted above, FCS managers knew at the outset of the program that its success or failure would depend in large measure on program leaders’ ability to enforce “SoS discipline” throughout the program structure. This objective was never fully accomplished, however.

Organizationally, IPTs Provided Necessary Balance of Roles for SoS Development

Despite problems with authorities and enforcement of SoS tradeoffs, the IPT structure provided what many officials believed to be a unique and appropriate set of organizational entities for the FCS’s broad mandate. The Army’s desire to build brigade-level capabilities was necessarily going to challenge past ways of building capabilities and

⁵⁷ Bourgoine et al., “The FCS One-Team Approach—The Linchpin for Program Management Success,” 2004, p. 9.

⁵⁸ Boeing Company, “Future Combat Systems (FCS) System Development and Demonstration (SDD) Phase Systems Engineering Management Plan (SEMP),” D786-10007-1, REV NEW, May 16, 2003, p. 21; and Bartley, “FCS-Equipped Unit of Action Complementary and Associate Programs,” 2004, pp. 22–23.

⁵⁹ Interview data.

⁶⁰ Interview data.

therefore required new relationships within the Army. The structures built in the FCS program provided a mix of system and system-of-system entities designed to break out of the historically stove-piped development structures and enforce a more holistic consideration of Army capabilities.

Government FCS Program Management Worked to Orchestrate Complex Relationships, Structures, and Expectations

While the novel LSI structure reflected the industry-government partnership aspect of FCS program execution, the Army also established a traditional Army Program Management Office to execute its oversight responsibilities. While the LSI led the FCS system-of-systems integration, the Army PM Office maintained overall responsibility for several key activities including, but not limited to, defining operational and SoS requirements, performing overall program management and resourcing, managing the program's acquisition strategy, managing program-level cost, schedule, and performance, managing test and evaluation, and coordinating all other government agencies supporting the FCS. Significantly, the Army also maintained "oversight and final approval of the LSI's subcontracting and competition plans."⁶¹

The Army Program Office, depicted in Figure 6.3 as it was configured in 2003, was designed to provide management oversight below the FCS system-of-systems level. The AAE designated Program Executive Officer (PEO), Ground Combat Systems (GCS) as the single, lead PEO. PEO(GCS) had primary oversight responsibility for ensuring timely program execution. PM FCS was tasked with ensuring that program milestones were met and was responsible for executing program schedule, cost, performance, and supportability.⁶²

The AAE vested the PEO(GCS) and PM FCS with authority to make resource allocation decisions based on FCS program needs. PM FCS (a one-star General Officer early in the program and elevated to a two-star in 2004) reported to PEO(GCS), which in turn reported to the Assistant Secretary of the Army for Acquisition, Logistics and Technology (ASA(ALT)).⁶³ A dotted-line (i.e., collaborative) relationship was maintained with DARPA during this early period in the Army FCS program.

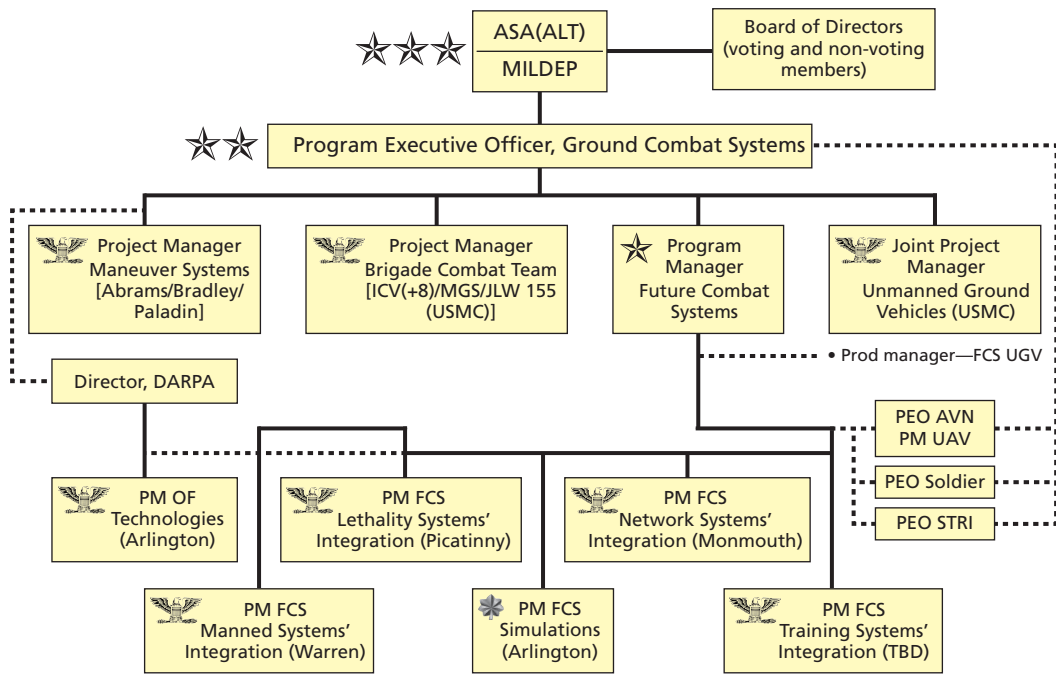
PEO(GCS) chaired an executive Board of Directors (BoD) to coordinate supporting activities undertaken by other PEOs. The BoD would meet at least quarterly to provide broad oversight of the program as well as to advise on synchronizing concurrent and complementary efforts. In addition to PEO leadership, the BoD's membership included TRADOC, Army staff elements, DCMA, Army Materiel Command,

⁶¹ *Acquisition Strategy Report Future Combat Systems*, 2003, p. 9.

⁶² *Acquisition Strategy Report Future Combat Systems*, 2003, p. 9.

⁶³ *Acquisition Strategy Report Future Combat Systems*, 2003, p. 9.

Figure 6.3
Government FCS Management Structure, May 2003



SOURCE: Acquisition Strategy Report Future Combat Systems, 2003, p. 41.

RAND MG1206-6.3

OSD, and the J-8.⁶⁴ Other government agencies could be brought into BoD meetings as warranted by program developments (e.g., Air Force representatives might attend to discuss FCS UA transportability). The BoD had weighty responsibilities for coordinating the FCS program within the Army and with other services.

Outside of the Army's FCS PM Office, the Army G-8 and the Military Deputy to the ASA(ALT) (MILDEP) established a complementary system oversight and management process. The two organizations signed an August 2003 MOA that, among other things, committed each of them to identify programmatic disconnects and funding shortfalls with complementary systems, and to ensure that baselines for the systems "include FCS key programmatic events as part of their program oversight."⁶⁵ The MOA also established a two-star General Officer-level Equipping Program Evaluation Group Synchronization IPT. (This organization was outside of PEO Ground Combat Systems and is thus not shown in Figure 6.3.) The G-8/ASA(ALT) Synchronization IPT was intended to resolve issues between FCS and other Army programs by

⁶⁴ Program Manager, Future Combat Systems, *Acquisition Strategy Report*, August 3, 2005, p. 52.

⁶⁵ Bartley, "FCS-Equipped Unit of Action Complementary and Associate Programs," 2004, pp. 23–24.

developing strategies for adjustments in program funding, schedules, or performance requirements. If such strategies were matters of dispute, they could be escalated to the AAE level for resolution. For issues outside the Army, the Synchronization IPT would convene to develop strategies and its recommendation to “the AAE in preparation for convening an Overarching IPT (OIPT), or joint OIPT, depending on the issue” in order to develop a course of action. Issues that could not be resolved at the OIPT level might be taken to “a special Defense Acquisition Board” for final decision.⁶⁶ However, FCS senior managers clearly understood that, particularly for interfacing challenges associated with programs controlled outside the Army, it was possible that disputes might be irresolvable.⁶⁷

The Project Managers depicted in Figure 6.3 (i.e., for Technologies, Lethality Systems’ Integration, Manned Systems’ Integration, etc.) were expected to maintain oversight of the LSI via the IPT process, and through the conduct of formal In Process Reviews. They would also employ an integrated set of processes, applications, and practices to measure an acquisition program’s cost and schedule performance: an Earned Value Management System (EVMS).⁶⁸ Project Managers in the Army structure sat on corresponding IPTs within the LSI structure; thus, they had combined roles of providing oversight of LSI performance while also participating in the LSI IPT process.

The Army believed its “unique relationship” with the LSI made the “EVMS a critical tool in determining the effectiveness of the partnership.” As described further below in the subsection on processes, EVMS data would be sought from multiple levels within the IPT structure.⁶⁹ Indeed, according to one program official, the government would act as an “independent assessor of schedule and budget [to keep the] LSI ‘honest.’”⁷⁰

Top-Level Organizations Were Useful to Army, Industry, and Government Senior Leaders

Some program senior leaders believed the One Team Council worked well in the LSI structure and might be a construct that could be replicated in future acquisition programs. The OTC brought together senior leaders from government and industry for coordination and collective decisionmaking.

⁶⁶ Bartley, “FCS-Equipped Unit of Action Complementary and Associate Programs,” 2004, pp. 23–24.

⁶⁷ As Bartley put it, when issues with complementary programs “fall outside the Army’s purview, sometimes a clear [course of action] is not apparent.” Bartley, “FCS-Equipped Unit of Action Complementary and Associate Programs,” 2004, p. 24.

⁶⁸ *Acquisition Strategy Report Future Combat Systems*, 2003, p. 39.

⁶⁹ *Acquisition Strategy Report Future Combat Systems*, 2003, p. 45.

⁷⁰ Khan, “Evolutionary Acquisition,” 2004, slide 28.

Despite early concerns that the FCS Board of Directors would be a “cumbersome” decision-making body,⁷¹ senior program officials we interviewed thought the BoD served a useful role during FCS. It was chaired by the commander of Army’s Capabilities Integration Center (ARCIC) (a three-star Army general) and met at least quarterly. The BoD brought together senior leaders from throughout the greater FCS community of interest to identify key FCS challenges and discuss which organizations could work solutions. The meetings also facilitated senior leader “buy in” to key decisions, and the AAE could resolve disputes if needed in the BoD forum.⁷²

Ad Hoc Governance Bodies Proved to Be Valuable Assets

Other examples of governing bodies created throughout the FCS program showed promise as well. The FCS “Team One” working group was formed around 2007 to fix the state of designs (particularly aspects of C2) and prepare them for PDR. Led by the FCS Chief Architect, Team One was essentially established as a troubleshooting organization after it became clear that existing integrating IPTs lacked authority to work across the program as needed. The Team One group framed and validated outstanding engineering design issues, and it directed development of plans, schedules, and occasionally the ECPs needed to drive design issues to closure. Different aspects of the FCS design were given to appropriate cross-IPT components of Team One, which later compiled all of their solutions into a system-of-systems design document. Team One essentially started from scratch on this work, given the program’s limited progress prior to its establishment, program officials said.⁷³ Team One was an example of FCS crisis management action, but it was also an example of the LSI organization’s ability to adapt in response to challenges.

The One Team Partnership Was Never Fully Realized

The Army intended to undertake a “new paradigm” in its FCS acquisition strategy. An unprecedented partnership between industry and government was deemed necessary to bring the best talent to the program and to execute its aggressive schedule. However, this objective was never fully accomplished, which resulted in some divestiture of government authorities.

The Army acquisition and requirements communities were distrustful during the FCS period—which hampered communication and feedback between the two

⁷¹ Schenk, “Army Systems Acquisition Review Council,” slide 53.

⁷² Interview data.

⁷³ Interview data.

groups—and remain so to this day.⁷⁴ Moreover, the LSI’s “honest broker” role was questioned early in the program when some subcontractors reported an atmosphere of competition with the LSI.⁷⁵ Program officials typically reported that they did not think the LSI was sufficiently committed to acting on the government’s behalf in a partnership role.⁷⁶ The Institute for Defense Analyses studied and reported on the relationship between the Army and the LSI. It noted that the government cannot expect contractors to act in its best interest in cases where such action could potentially conflict with their corporate financial interests.⁷⁷

Within the LSI structure, the partnership experience on IPTs varied depending on a participant’s position in the tiered construct. Government and industry officials working at the first and second tiers in the structure reported that they had good working relationships and generally achieved consensus on key program decisions. However, at lower levels, government IPT co-leads reported feeling outnumbered by the LSI. They stated further that mid-level IPT leaders discouraged the elevation of issues to higher levels for resolution and that some of the Army’s middle-level managers (e.g., at the lieutenant colonel level) were at times reluctant to pass difficult problems up the chain because such actions might have had a limiting effect on their careers. Some government officials also believed that senior leaders in the program actively sought to promote a harmonious program environment, which had the effect of discouraging dissent.⁷⁸

Government officials working at lower levels in the LSI structure felt that the established command environment (e.g., discouraging conflicts—or the reporting of conflicts—within the One Team) and related program policies of driving decision making to low levels had the effect of divesting too much authority to the LSI. Government co-leads on IPTs were not empowered to use their fiduciary oversight responsibilities to challenge decisions by the LSI IPT leads. If consensus could not be reached, the LSI could ignore nonconcurrence by government co-leads and move forward with its proposed solution to any issue. In such cases, the government IPT member could escalate a dispute for resolution at higher levels, to include, ultimately, the Army PM level, but all program officials we interviewed stated that such decisions to escalate

⁷⁴ Interview data.

⁷⁵ Flood and Richard, 2006, p. 365.

⁷⁶ Interview data.

⁷⁷ In the case of FCS, IDA recommended that the Army take steps to “ensure that it has, and continually uses, a competent internal capability to develop a corporate Army position on key FCS issues” such as measuring program status and trends as well as independent operational testing. David R. Graham et al., *IDA Review of FCS Management: Volume I*, Alexandria, Va., Institute for Defense Analyses, August 2004, p. 35. See also Paul L. Francis, “Defense Acquisitions Future Combat Systems Challenges and Prospects for Success: Testimony Before the Subcommittee on Airland, Committee on Armed Services, U.S. Senate,” Washington, D.C., GAO-05-442T, March 16, 2005, p. 7.

⁷⁸ Interview data.

were rare.⁷⁹ Indeed, one government IPT co-lead stated that the LSI leads on IPTs had contract authorities, and controlled funding and subcontractors, such that they could ignore direction from their government colleagues.⁸⁰ Another government IPT official managing part of the MGV program stated that he felt that he essentially had “zero authority” to challenge his LSI IPT leader.⁸¹

It is apparent that the FCS program environment undermined a key premise behind the IPT concept and the program management functional and hierarchical structure. The premise involves the following three principles:

- Management takes place at all relevant tiers.
- Each tier at a minimum reports to both the tier above it and below it so that significant program status and issues propagate through all tiers, eventually up to senior managers.
- Program status and issues are reviewed as required by senior managers.

Regardless, some government IPT co-leads felt that because they were discouraged from reporting technical and other challenges to higher levels in the IPT structure, program senior leaders were not sufficiently informed of the serious issues being confronted at lower levels in the program.⁸² While many former program officials believed the LSI was, at the time, the best conceivable framework to execute FCS, they also felt that the program’s senior leaders maintained a management attitude that ultimately undermined the program’s performance. The LSI’s mindset was that managers needed to maintain a positive attitude to keep people motivated rather than dwelling on problems.⁸³ Similarly, Army managers sought to maintain One Team harmony.⁸⁴

Government Personnel Were Top-Notch, but Shortfalls Complicated Management Functions

The Army Program Office was staffed by 283 core civilians and 35 core military personnel in fiscal year 2003, with “matrix support” provided by 205 additional civilians who were employees of other organizations.⁸⁵ Program documents and reports indicate

⁷⁹ Interview data.

⁸⁰ Interview data.

⁸¹ Interview data.

⁸² Interview data.

⁸³ Interview data.

⁸⁴ Interview data.

⁸⁵ U.S. Army, Department of the Army, Program Executive Office Ground Combat Systems, *FY03 Historical Report*, p. 4.

that the government faced significant challenges in staffing midway through the program and that it periodically faced “critical” personnel vacancies, such as chief engineer, lead systems engineer, and SoS integration staff.⁸⁶

The program office’s staffing grew steadily and exceeded 870 personnel (government and contractors) by 2009. However, the government staff was dwarfed throughout the program by the size of the LSI and subcontractor staff. Program documents indicate that the LSI exceeded 5,000 personnel in 2005, for example,⁸⁷ and eventually involved over 10,000 LSI and subcontractor personnel in the program. Part of the rationale for use of the LSI construct was the contractor’s ability to leverage industry expertise and numbers to compensate for government personnel shortfalls.

Personnel Problems Included a Shortage of Workers and Skills

It has been widely acknowledged that quality personnel are the linchpin of a complex acquisition program.⁸⁸ Indeed, according to the GAO, “getting the right people in place at the right time and supporting them with the requisite resources is critical.”⁸⁹ Former FCS officials generally agreed that the LSI succeeded in bringing industry leaders and their top talent to the FCS program. And for that matter, the Army generally managed to recruit the best talent from its service and from the wider DoD acquisition community as well. However, the personnel “bench” was not deep, particularly on the government side.

Some six years into the program, the GAO found that the government remained “disadvantaged in terms of workforce and skills” on FCS.⁹⁰ Interviews with former program officials and Army documents from the period indicate that the program had trouble recruiting experienced engineers (particularly network engineers) and other staff with specialized skills to support the government program office—particularly engineering skills below the rank of LTC and civilians in the GS-9 through GS-11 grades.⁹¹ Former program officials almost uniformly stated that while they did get the

⁸⁶ See, for example, Major General Charles Cartwright, PM FCS (BCT), “ALTESS AIM Probability of Success,” slide presentations, 2006 to 2007.

⁸⁷ U.S. Army, Department of the Army, Program Executive Office Ground Combat Systems, *PM, UA Historical Report FY 2005*, no date, p. 7.

⁸⁸ Stephen P. Welby, Deputy Assistant Secretary of Defense for Systems Engineering, “The Role of Systems Engineering in Creating Successful Defense Acquisition Programs,” remarks before the International Council on System Engineering, Los Angeles Chapter, Los Angeles, Calif., August 9, 2011.

⁸⁹ Government Accountability Office, Report to the Committee on Armed Services, U.S. Senate, *Defense Acquisitions: Strong Leadership is Key to Planning and Executing Stable Weapon Programs*, Washington, D.C.: Government Accountability Office, GAO-10-522, May 2010, p. 31.

⁹⁰ Francis, “Defense Acquisitions Future Combat Systems Challenges and Prospects for Success,” 2005, p. 7.

⁹¹ Carol Lufburrow, Department of the Army, PM FCS (BCT) Manpower Lead, “Information Paper,” SFAE-GCS-UA-SP3, April 15, 2006, p. 1.

“pick of the litter” among government experts,⁹² they did not have adequate numbers to staff the program.⁹³ Being shorthanded, Army program managers were forced to work the staff they did have to the breaking point, at times creating a very difficult work environment. They also had to place junior government staff in positions where more senior and experienced personnel were needed.⁹⁴ According to one senior engineer, even the O-5 and O-6 level Army officers managing SoS components and undertaking cross-cutting functions often did not have the requisite expertise to execute their tasks.⁹⁵ One Army product manager expressed surprise at the size of the budget he controlled as a colonel—roughly \$800 million over a period of six years, he said.⁹⁶

The government was particularly short on technical experts needed to co-lead the IPTs managing system engineering, system architecture, software development, and the IPTs overseeing testing.⁹⁷ Moreover, as detailed below, repeated changes to the FCS program content and budget forced program managers to make unplanned expenditures and to divert technical personnel from their primary tasks.

The government has since acknowledged the risks associated with employing inexperienced program managers for complex acquisition efforts.⁹⁸ In the case of FCS, the government’s shortage of personnel with requisite technical expertise and acquisition experience meant that it was not sufficiently capable of validating or challenging materiel solutions proposed by the LSI.⁹⁹ And the government’s shortage of acquisition talent remains to this day. In 2011 the GAO reviewed 44 major defense acquisition programs and determined that just 23 were able to fill all authorized positions.¹⁰⁰

Multiple Restructurings Challenged All FCS Managing Bodies

The FCS program experienced multiple restructures from 2003 onward, as detailed elsewhere in this report. The program’s major restructurings had a significant impact on its management. According to former senior program officials, each major change forced the program to divert significant resources to replanning. This exercise could

⁹² Interview data.

⁹³ Interview data.

⁹⁴ Interview data.

⁹⁵ Interview data.

⁹⁶ Interview data.

⁹⁷ Interview data.

⁹⁸ Andrew Tilghman and Marcus Weisgerber, “DoD Urged to Rethink Acquisition Managers,” *Defense News*, May 2, 2011.

⁹⁹ Interview data.

¹⁰⁰ Senior GAO official, remarks at the RAND Corporation, Arlington, Va., September 8, 2011.

require six months or more, and it forced IPTs to execute their programs based on an obsolete plan in the meantime. Budget cuts in particular prompted the LSI to generate Budget Change Requests, which typically pushed to the out years projects that were determined to be unaffordable, given new budget realities. In so doing, promised FCS capabilities were pushed off as well.¹⁰¹

There were significant expenditures on the bids and proposals that were generated to implement the adjusted program. The LSI contract had to be renegotiated in response to the changes, which forced government contract specialists to divert from their contract monitoring duties and undertake contract renegotiations. Similarly, program engineers were diverted from their work advancing FCS to evaluating changes to the program. Indeed, FCS restructures diverted vital management resources from their primary role of executing the program.¹⁰²

Finally, with respect to the spin-outs, the LSI's role in the program changed in an important way. The Army's original intent was to have the LSI focused on the integration of subcontractor products. However, in 2007, the Army decided that the LSI should act as the prime contractor for the first spin-outs. The LSI would also be the prime for low-rate production of FCS core systems, the Army determined. The GAO found that this "was a significant change from the early steps taken to keep the LSI's focus on development."¹⁰³ Interviews with some officials noted that the change in the LSI's role may have created uncertainty, tension, and trust issues with major subcontractors.¹⁰⁴

Another key change in the program was the Army converting the OTA contract to a FAR-based contract in 2005. Early in the program, the Army officials believed the schedule and complexity of the FCS program demanded the use of the OTA, which permitted innovative business practices and management flexibility. However, certain influential members of Congress had become concerned that the OTA afforded government less oversight than would be the case in a more traditional FAR-based contract, and that the LSI might be inclined to pursue its own financial interests instead of acting on the Army's behalf as the SDD program progressed to production. The Congress thus pressured the Army to convert its OTA contract with the LSI to a FAR-based vehicle.¹⁰⁵ The Army completed this conversion on September 30, 2005.¹⁰⁶ In the view of one senior program official, the conversion stripped managers of the flexibility

¹⁰¹ Interview data.

¹⁰² Interview data.

¹⁰³ Francis, "Defense Acquisitions: Issues to Be Considered for Army's Modernization of Combat Systems," 2009, p. 8.

¹⁰⁴ Interview data.

¹⁰⁵ George Cahlink, "Future Combat Zone," *Government Executive*, April 15, 2005, pp. 57–58; and Jen DiMascio, "McCain Questions FCS Commercial-Item Procurement Strategy," *Inside the Army*, March 7, 2005.

¹⁰⁶ Department of Defense Inspector General, *Contracted Advisory and Assistance Services*, p. 6.

required to manage the FCS program to meet cost, schedule, and performance goals. Program managers could no longer quickly move requirements from one subcontractor to another to improve technical performance, for example. In addition, the FAR's more laborious reporting rules contributed to FCS schedule slippage.¹⁰⁷

Army and LSI Program Management Structures Evolved Significantly and Constructively Throughout Program Changes

During the first two years post–Milestone B, PM FCS was made a direct report to the AAE (an equivalent position to other PEOs) and, accordingly, the PM's rank was increased from brigadier to major general. As depicted in Figure 6.4, project director positions were created at lower levels of the structure, and four deputy PMs were established to support the PM.¹⁰⁸ Other organizational changes occurred as well, such as the addition of a complementary programs organization and a project director position to manage the spin-out programs that reported to PM FCS.¹⁰⁹ The evolution in the PM structure and the FCS program manager's increased rank indicated the Army's appreciation of the importance of the program to the Army, the size compared with other programs, and its increasing complexity.

The LSI structure also evolved over time and showed flexibility with its ability to adapt. Figure 6.5 shows a 2005 iteration of the LSI's top tier organizations. A chief analyst position was added to bolster the program's analytical support to requirements and performance assessments, design trades, and to SoS integration activities. Notably, a government counterpart to the chief analyst position was lacking.

A second tier level group was established to manage the spin-out effort. A DCMA organization—the DCMA FCS Program Integration Office (PIO)—was formally positioned at the top tier, deputy program manager level. However, DCMA was not part of the LSI construct. Rather, it performed an independent role as DCMA, the DoD's executive agent for earned value management. It worked *with* both the Army PMO and the LSI, but did not work *for* either organization. It was charged with identifying potential risks to cost, schedule, and performance experienced at any level in the LSI structure.¹¹⁰ We address how cost, schedule, and performance incentives were dealt with in the FCS program in Chapter Seven.

According to a former senior DCMA official, some elements of the FCS program initially opposed DCMA oversight, believing that the government-industry partner-

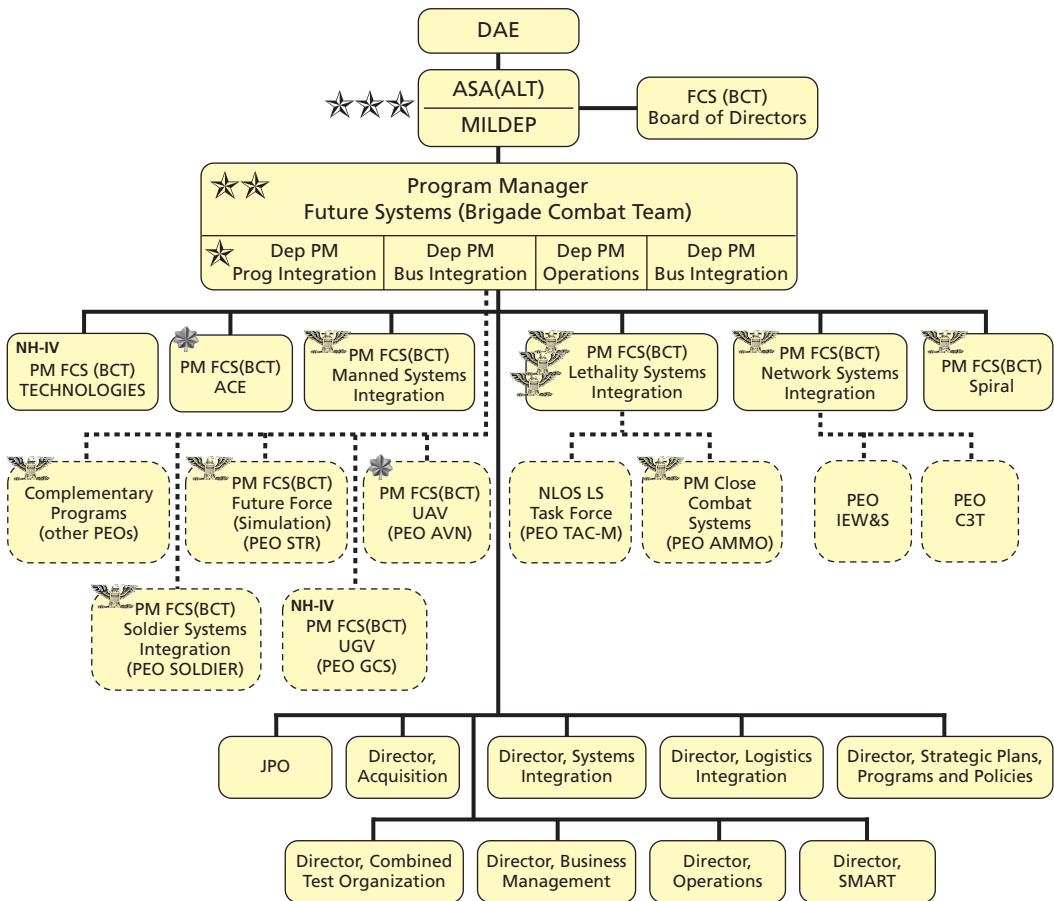
¹⁰⁷Interview data.

¹⁰⁸Department of the Army, Program Manager, Future Combat Systems, *Acquisition Strategy Report Future Combat Systems*, D786-10160-1, Rev 1, August 3, 2005, p. 46. Not available to the general public.

¹⁰⁹Department of the Army, Program Manager, Future Combat Systems, *Acquisition Strategy Report Future Combat Systems*, August 3, 2005, p. 44.

¹¹⁰Bourgoine et al., "The FCS One-Team Approach—The Linchpin for Program Management Success," 2004, p. 11.

Figure 6.4
Government FCS Management Structure, September 2005

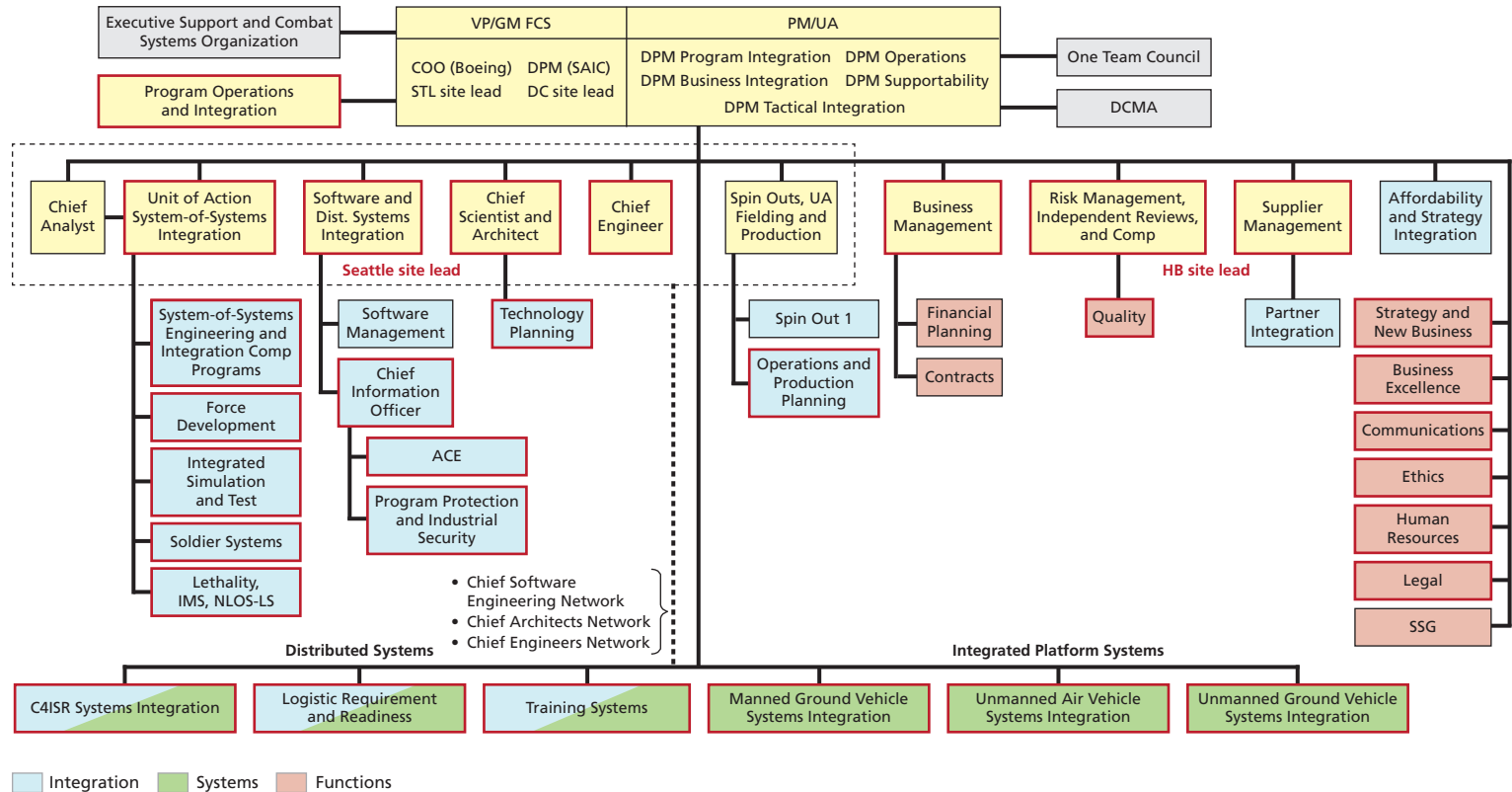


SOURCE: Program Manager, Future Combat Systems, *Acquisition Strategy Report*, August 3, 2005, p. 46.
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ship approach largely obviated the need for it. However, the transition to a FAR-based contract required DCMA to play a more formal role in contract administration.

With its position solidified in the program, DCMA undertook some innovative approaches to support the Army program management office, former senior DCMA officials said. One such innovation was the creation of a tripartite MOA between the Army, LSI, and DCMA. This was unprecedented. Typically DCMA would complete a MOA solely with its government counterpart. In this traditional arrangement, the DCMA contract management office (CMO) in each contractor place of operation would report contract performance data directly to the program’s Army (or other service) program management office. With 25 reporting contractors, this would have overwhelmed the Army PMO in the case of FCS, senior DCMA officials said. Thus,

Figure 6.5
FCS LSI Organization, March 2005



SOURCE: Program Executive Office Ground Combat Systems, FY03 Historical Report, p. 6.
 NOTE: Boxes outlined in red are linked to their lower-tier organization charts and RAAs.
 RAND MG1206-6.5

under the terms of the MOA for FCS, CMOs at each contractor site reported performance data to the program-level, DCMA FCS PIO (see Figure 6.5). This arrangement significantly improved the DCMA visibility into the program. It therefore enabled DCMA to monitor contractor performance and direct adjustments as needed. This function typically would have been performed by the Army PMO; the PMO's burden was thus reduced. Similarly, instead of overwhelming the Army PMO, DCMA FCS PIO managed the 25 CMO inputs and aggregated them for reporting to both the Army PMO and to DCMA/OSD channels.

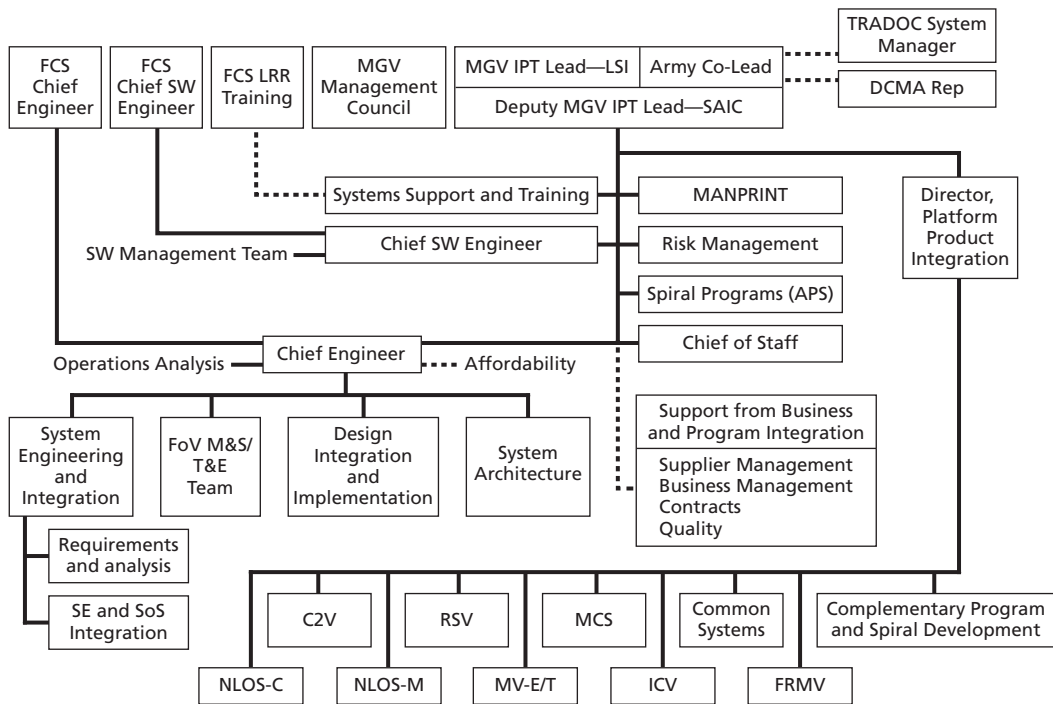
As indicated in Figure 6.5, the number of organizations with integration responsibilities increased compared with the 2003 structure, reflecting the program's expanding focus on the SoS integration challenge. Considered together, Figures 6.5 and 6.6 shed further light on the LSI's design for SoS integration. In this regard, the top tier depicted in Figure 6.5 consists of the senior program managers responsible for the FCS SoS. The second tier managers were responsible for the capabilities and other major groups of deliverables (e.g., MGV, UAV, UGV, and C4ISR) that would comprise the SoS; many of these managers also had significant integration responsibilities. In Figure 6.6, the second tier MGV IPT lead is shown along with the third tier IPTs responsible for individual platforms in the MGV program such as the Command and Control Vehicle (C2V) and the Infantry Combat Vehicle (ICV). It is notable that O-5 level officers were charged with managing the platforms, which were large acquisition projects.

Each IPT tier depicted in Figures 6.5 and 6.6 had functional components responsible for important cross-cutting activities such as system architecting, system engineering, and software, as appropriate, providing a matrix organizational structure. The structure included a significant component of SoS engineering throughout, as indicated by the connectivity between the Chief Engineer and Chief Software Engineer in the second tier and their third tier counterparts shown in Figure 6.6, and by the Chief Engineer and Chief Software Engineers' network shown in Figure 6.5, for example.

FCS Program Management Processes Were Hindered by Standard Practices and New Tools

The FCS program adopted some novel acquisition strategy approaches and developed an innovative LSI structure to execute the project. However, in the case of key program management processes, FCS managers attempted to implement standard practices of the time and use then-state-of-the-art program management tools. Below we describe the employment of select processes and tools that significantly influenced the FCS program outcome in the view of former program officials, or those who were identified as essential by the Army. These processes and tools consist of system engineering and architecting, to include interface control management, and the use of the EVMS and Dynamic Object-Oriented Requirements System (DOORS) systems. In all cases, the

Figure 6.6
MGV IPT Structure, March 2005



SOURCE: The Boeing Company, “FCS SDD Organization . . . Building One Team,” briefing slides, SDD Org/RAA Document—Rev K, March 5, 2005, Slide 3.

RAND MG1206-6.6

program’s execution of essential processes and employment of key tools was challenged by the FCS project’s vast scope and compressed schedule. In the end, the FCS program was challenged to implement standard practices, and many new processes and techniques were necessary.

System Engineering and Architecting Were Challenged to Meet FCS Schedule Goals

The FCS 2003 System Engineering and Management Plan (SEMP)¹¹¹ documents how the LSI/Army team intended to conduct the FCS system engineering. The SEMF follows the generally accepted DoD practices of that time,¹¹² tailored to FCS needs. The depiction¹¹³ of the “V” paradigm for FCS synthesizes this process well; it is shown in

¹¹¹ Boeing Company, “Future Combat Systems (FCS) System Development and Demonstration (SDD) Phase Systems Engineering Management Plan (SEMP),” D786-10007-1, REV NEW, May 16, 2003.

¹¹² Department of Defense, Under Secretary of Defense for Acquisition, Technology, and Logistics, *Department of Defense Instruction 5000.2*, “Operation of the Defense Acquisition System,” April 5, 2003.

¹¹³ FCS SoS Engineering and Integration IPT, “FCS SoS Assessment,” briefing slides, February 2006.

Figure 6.7 and conforms to the more general V depiction found in DoD acquisition guidance from the period.¹¹⁴

In the figure, time moves from left to right. The major program reviews that occur as time evolves are shown on the bottom. Thus PDR is preceded by SRR and followed by CDR. The process unfolds by traversing the V; that is, by traveling down the left-hand side (generally called the design side) of the V and then up the right-hand side (generally called the verification side), and in so doing its projection on the horizontal axis moves with time from left to right. The V depiction is popular because it captures some very important features of the system engineering and architecting (SE&A) process.

As indicated in Figure 6.7, work on requirements precedes the initiation of specifications and design work (as indicated in the first box, which pertains to operational requirements documents, etc.). For a system-of-systems, architecture and engineering establish the requirements for the SoS components (e.g., in the case of FCS, requirements for the MGV platforms and the network). Component requirements should be set before component design is initiated. However, driven by the program's aggressive schedule goals, FCS program managers took a riskier approach.

Time savings were created early in the FCS program by limiting the upfront SE&A needed to allocate component requirements so that component designs would support the FCS system-of-systems specification. In addition, program senior leaders did not want to make the expenditures needed to support the engineering work force that would be needed to conduct upfront analysis.¹¹⁵ The LSI thus began the process of executing contracts for major FCS components even as foundational SE&A continued.¹¹⁶ As a result, and as detailed in the requirements discussion, technical specifications were simultaneously established for the SoS and for some of the SoS systems (components), with no assurance that the two sets of specifications could be harmonized.¹¹⁷

Because key deliverables were built before necessary SoS engineering was completed, considerable reworking and reconciliation of FCS platforms and deliverables was required as the program progressed. The reworking was conducted at significant expense.¹¹⁸

PDR was not completed for all major FCS systems until fiscal year 2009. By that time, several component prototypes for testing had been produced as well; these included the UGS, UAV, UGV, NLOS-LS, and the supporting battle command sys-

¹¹⁴ Department of Defense, Defense Acquisition University, *Defense Acquisition Guidebook*.

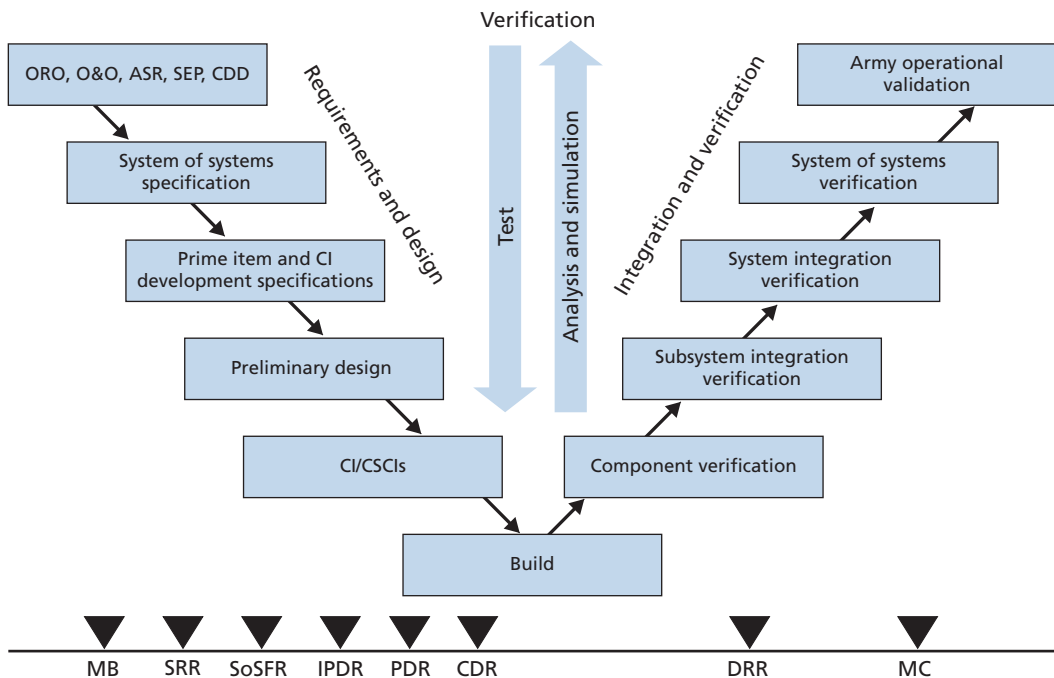
¹¹⁵ Interview data.

¹¹⁶ Department of the Army, Program Executive Office Ground Combat Systems, *FY03 Historical Report*, no date, p. 3; and interview data.

¹¹⁷ Interview data.

¹¹⁸ Interview data.

Figure 6.7
FCS Systems Engineering Framework



SOURCE: FCS SoS Assessment, A Briefing, SoS Engineering and Integration IPT, February 2006.

RAND MG1206-6.7

tem.¹¹⁹ A system-of-systems PDR was also completed in 2009, well past the initially intended date of 2004.¹²⁰ The PM saw the SoS PDR as significant, but by that time, the program had been significantly restructured and major portions cancelled.¹²¹

Preparatory System Engineering and Architecting Was Inadequate

Every veteran of the FCS program that we spoke to on SE&A agreed that the entire project was hamstrung by the rush to get contracts in place early, which pushed both hiring and early product building before preparatory system engineering had been completed. SoS engineering should have been much stronger early in the program in order to produce integrated design tradeoffs and changes to inform management deci-

¹¹⁹ While the network PDR was “officially” carried out, it is not clear that the event constituted a true design review, since there were so many outstanding, high-risk action items.

¹²⁰ U.S. Army, Department of the Army, Program Executive Office Ground Combat Systems, *FY09 Historical Report PM Future Combat Systems*, no date, p. 9.

¹²¹ Major General John R. Bartley, PM FCS (BCT), “ALTESS AIM Probability of Success,” slide presentation, July 16, 2009, slide 49.

sions.¹²² Moreover, the schedule compelled the program to provide some product specifications before they were properly developed by system engineering specification allocation best practice. Best practice would have allocated product specifications up front so that product managers understood what was technically required of their products. Ultimately, there was serious “misalignment” between the concurrently developed SoS and product specifications, and no good mechanism for adjudicating the disconnects, FCS officials discovered.¹²³

Several former program officials also pointed to the following specific flaws in SE&A and other essential processes as they were practiced in FCS:

- Because subsystem requirements were allocated before front-end system architecting and system engineering was accomplished, PDRs were largely invalidated¹²⁴ and, later, the achievement of SoS requirements was placed at serious risk.
- Detailed subsystem designs were allowed to proceed before rational, traceable subsystem design requirements were established, and/or such subsystem design requirements were properly established but with the use of improper product specifications as their starting baseline.
- Detailed subsystem designs were allowed to proceed before adequate component and lower subsystem technology baselines were established, in many cases due to immature technology, which precluded an adequate understanding of engineering and integration issues.
- Some subsystem managers independently determined which subsystem requirements they would choose to meet, which would have ultimately put the FCS system-of-systems at risk.

The government’s shortfall in personnel with SE&A experience and expertise also contributed to the problem. According to a senior official, had the U.S. government had more experienced personnel on the program, it is possible that they could have demanded more upfront, systematic SE&A. Instead, senior leaders—driven by schedule demands—chose to authorize just enough SE&A to launch the program.¹²⁵

While the FCS experience highlights the importance of upfront SE&A, it is certainly not clear whether that would have saved the FCS program. In hindsight, perhaps the outcome might have been that the significant technical and operational challenges in FCS were determined earlier and with less overall cost to the Army.

¹²²Interview data.

¹²³Interview data.

¹²⁴The PDRs were not valid because they were performed under the assumption that the PDR product specifications were adequate to assure SoS specification compliance. Such assurance was unlikely, however, given that product specifications were not allocated from the SoS specification in many instances.

¹²⁵Interview data.

State-of-the-Art Tools Were Sought to Solve Complex Program Management Issues

The three key measures of an acquisition program's health are cost, schedule, and technical performance. State-of-the-art tools were used to track such performance on the FCS program. EVMS tracked cost and schedule, while DOORS was employed to manage and track the program's specification tree from the SoS to the lowest specified levels. However, despite their establishment as standard tools for program management, neither tool was used properly on FCS.

The Army believed EVMS would be a vital tool for managing the FCS program. An element of the One Team approach included the use of a single EVMS software package and process to plan, monitor, and manage the cost and schedule aspects of the program.¹²⁶ All firms with subcontracts worth more than \$5 million were required to use EVMS to manage their portion of the program. Subcontractors reported their earned value information to the LSI for review.¹²⁷ EVMS data would be reported to senior managers on a monthly—and later weekly—basis.¹²⁸

In an evaluation last updated in January 2009, the White House Office of Management and Budget (OMB) reported the following with respect to the FCS program's employment of EVMS:

The Army measures the health of FCS through its Cost Performance Index (CPI) and Schedule Performance Index (SPI) as part of the EVM. EVM is a technique that measures a program's actual costs and schedule performance by comparing it with "planned" costs/schedule baselines. EVM accomplishes this by assigning each work step a cost and time limit, and then measuring actual cost/times for that work step against planned allocations. A 100% score of the actual work and actual cost in a program was accomplished at the planned cost and within the planned time-frame. *The Army's goal is to have a score of greater than 95% for both CPI and SPI.* CPI quantifies the Budgeted Cost of Work Performed divided by the Actual Cost of Work Performed. Both indexes are adjusted with official changes to the overall program (emphasis added).¹²⁹

The OMB report notes that a 2005 Army Audit Agency audit had determined that FCS had "effectively implemented earned value management in the early development stages of the program."¹³⁰ The OMB report cites the Army's lofty goal of achiev-

¹²⁶U.S. Army, Department of the Army, Program Executive Office Ground Combat Systems, *PM, UA Historical Report FY 2005*, no date, p. 4.

¹²⁷Boeing FAR contract, p. 20.

¹²⁸Schenk, "Army Systems Acquisition Review Council," slide 40.

¹²⁹The White House, Office of Management and Budget, "Detailed Information on the Future Combat Systems/Modularity Land Warfare Assessment," 2005.

¹³⁰The White House, Office of Management and Budget, "Detailed Information on the Future Combat Systems," 2005, Section 3.1.

ing CPI and SPI scores higher than 95 percent. It states further that for fiscal year 2007, the FCS program actually exceeded its goal and achieved a CPI score of 100.4 percent and an SPI of 99.1 percent. OMB reported that for fiscal year 2008, actual CPI and SPI scores were each 99 percent. The Army's own documentation in Defense Acquisition Executive Summary (DAES) reports covering October 2004 to April 2009, and as depicted in Figure 6.8, shows similarly impressive CPI and SPI scores over time.¹³¹

Projecting final program cost is one of EVMS's key capabilities. In this regard, Figure 6.9—also generated from data reported in DAES—depicts stable and closely aligned Army Program Office- and LSI-generated Estimate at Completion (EAC, the program's final projected cost) figures during the period approximately August 2004 to July 2008.¹³²

Tools Could Not Cope with Constant Program Content and Cost Changes

Notwithstanding the impressive cost and schedule performance reporting depicted above, FCS confronted serious technical challenges, schedule slippage, and cost growth. Turbulence experienced by the program in the form of repeated changes to its content and budget substantially accounted for schedule and cost changes. These changes in the program were well known:

The FCS program has evolved since Milestone B through multiple restructures/adjustments. . . . The changes have resulted in continuous updates to the contract Performance Measurement Baseline and have caused other program inefficiencies.¹³³

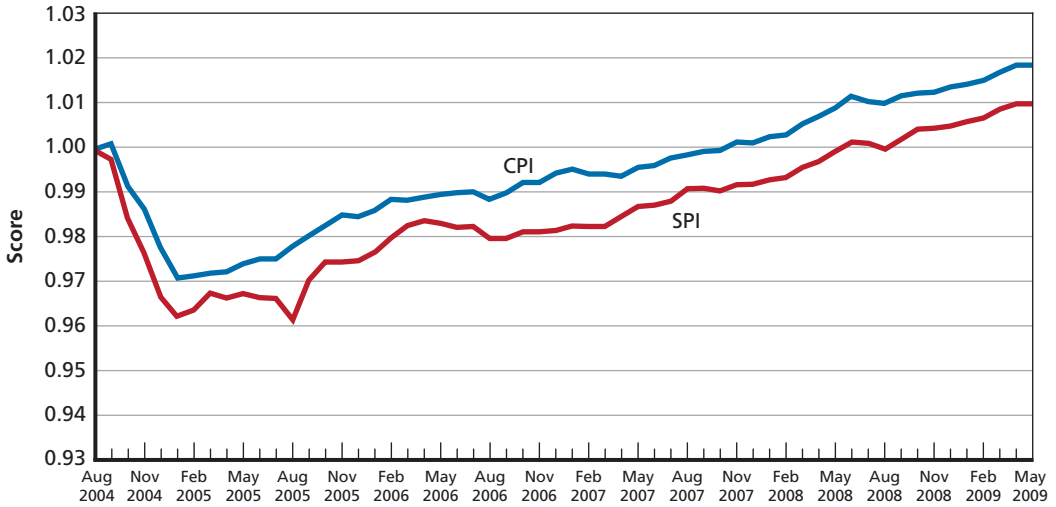
The structure and content shifted so often, EVMS targets were continuously being moved and shifted over time. What that meant from a management perspective is that while the CPI and SPI plotted below were reflective of the plan at a point in time, they reflected different programs *over* time as the program was rebaselined and requirements and work packages were pushed forward. In essence, the reporting could not reflect the turbulence and long-term effects of the shifting program. Veteran program officials almost uniformly stated that FCS was in fact too complex and subject to too much turbulence for effective EVMS implementation. Regarding complexity, some 25 of the One Team partners reported their EVMS performance data to the LSI, initially on a monthly basis and later, at the LSI's direction, on a weekly basis. The LSI would "roll up" (aggregate) the data for reporting to program senior leaders. However, the process had inherent flaws; these ensured that performance reports were not entirely accurate. To begin with, reporting from the 25 partners was weighted equally. Yet,

¹³¹ Defense Acquisition Executive Summary (DAES) reports from November 2003 to August 2009.

¹³² DAES reports from November 2003 to August 2009.

¹³³ Bartley, "ALTESS AIM Probability of Success," 2009, slide 4.

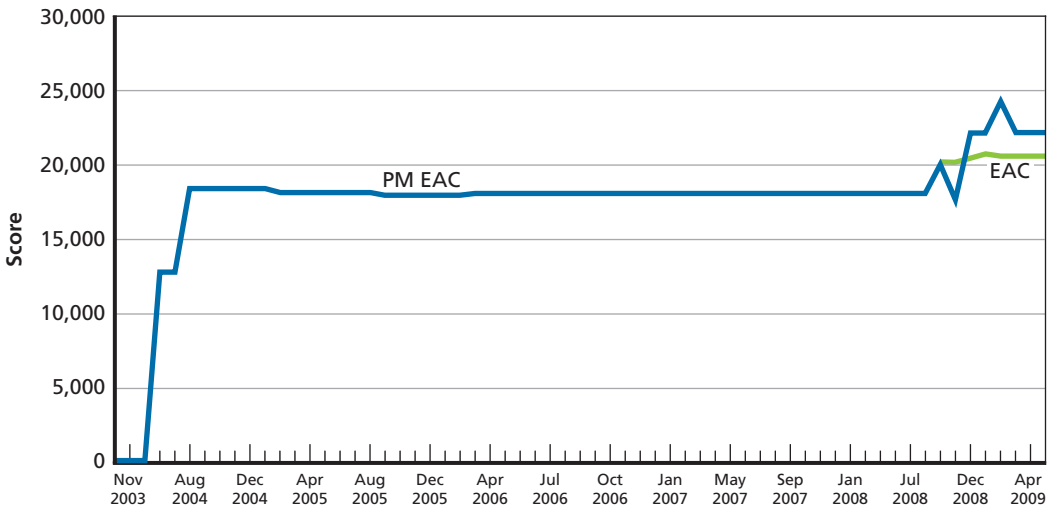
Figure 6.8
FCS SPI and CPI over Time



SOURCE: RAND analysis of information from DAES reports.

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Figure 6.9
FCS Estimate at Completion over Time



SOURCE: RAND analysis of information from DAES reports.

RAND MG1206-6.9

some partners' programs and products were much more important to achieving FCS technical performance than others. DCMA officials stated that without weighting, underperformance by vital programs could be obscured in reports to senior leaders. In addition, each of the reporting partners used their own, DCMA-approved business and EVM systems. Because of this, submitted data packages were not uniform. The LSI, therefore, had to undertake a complex and time-consuming exercise to harmonize the disparate data for aggregation. With just one week to complete the process, errors inevitably found their way into the rollup report.

EVMS inflexibility was another shortfall. EVMS could not keep up with the program's dynamic environment, in part because it took months to reprogram EVMS to account for major changes of the type described above.¹³⁴ FCS EVMS was thus destabilized and was not a good indicator of program health.¹³⁵ The superior performance numbers that EVMS generated nonetheless were produced because program managers continuously replanned and rebaselined FCS in response to major changes.¹³⁶

DOORS is employed to ensure that a requirements architecture is consistent, that is, that requirements have been allocated/decomposed from SoS technical requirements to the tiered components that comprise the SoS such that requirements realization at lower levels assures requirements attainment at higher levels and, eventually, requirements attainment at the SoS level. Following the classical V paradigm for system engineering, when technical problems in design preclude the satisfaction of lower tier requirements, risk mitigation and tradeoffs at various levels are initiated to assure SoS requirement satisfaction by other means.

The V paradigm was the process planned for FCS acquisition, and DOORS was intended to track the status of SoS and component requirements. However, several former program officials reported that DOORS could not be utilized as envisioned. Given the FCS project's scope and complexity, it initially took months to program DOORS to represent the project. Thereafter, when the program changed (e.g., during major restructurings), it could take months just to reprogram DOORS. In other words, reprogramming demands ensured that DOORS could not provide timely data to FCS program managers for months at a time.

Even more important, some program officials deviated from best practices in a way that undermined the utility of the DOORS system. In order to meet the aggressive schedule established for FCS, program officials were compelled to simultaneously establish technical specifications for the SoS and for some of its components. This

¹³⁴Past RAND research has determined that even for programs less complex than FCS, a key EVMS limitation is its "inability to quickly and effectively implement changes" and that "many other updating problems persist" for EVMS. Mark V. Arena et al., *Monitoring the Progress of Shipbuilding Programmes: How Can the Defence Procurement Agency More Accurately Monitor Progress?* Santa Monica, Calif.: RAND Corporation, 2005, p. 37.

¹³⁵Interview data.

¹³⁶Interview data.

being the case, DOORS could not be used as intended, as it was designed to monitor a standard flowdown of SoS technical requirements to the SoS components in accordance with defense acquisition's best practices. Put another way, effective implementation of DOORS depended on system requirements being properly inherited from and traceable to SoS requirements, neither of which were achievable given the short timelines and aggressive schedule chosen for FCS.

Program Management Tools Showed Mixed Performance

The broad mandate to develop brigade-level capabilities, and the aggressive timeline to do so, levied significant challenges on SE&A processes. The EVMS and DOORS programs were employed to support FCS program management, but in the end they were not used effectively and failed to provide essential performance information to program managers in a timely fashion.¹³⁷ Some program managers turned to other tools, such as the Integrated Master Schedule (IMS), in order to monitor their performance.¹³⁸

Other FCS tools had much better success. Communications up and down the LSI chain may not have been conducted as envisioned, given the program environment. However, the Advanced Collaborative Environment collaborative mechanism was viewed as a qualified success.¹³⁹ The ACE permitted users at hundreds of sites across the United States to access up to 16 levels of data, depending on their level of authorization. Program officials said that the ACE system saved the program money by, among other things, providing a virtual environment for collaboration, which reduced the need for personnel to travel in order to work in teams.¹⁴⁰ One user believed that the ACE had a superior capability for tracking the "workflow" of essential program documents. In this regard, the ACE afforded transparency on document development and collated stakeholder comments on documents as they were staffed. There were also some detractors. ACE was seen by some as cumbersome to navigate and sophisticated searches difficult to execute. Legacy ACE systems are still in use. Both TARDEC and the Army's GCV program office use versions of ACE for collaboration and information sharing.¹⁴¹

¹³⁷In a report to Congress on DoD's more general earned value management performance, the department stated that the "utility of [earned value management] has declined to a level where it does not serve its intended purpose." It stated further that program managers need an EVM process that "measures the quality and technical maturity of technical work products instead of just the quantity of work performed." The report was issued in September 2009. It is described and cited at Defense Acquisition University, "Performance-Based Earned Value." As of September 22, 2011:
<http://pb-ev.com/DoDEVImplementationReport.aspx>

¹³⁸Interview data.

¹³⁹Interview data.

¹⁴⁰"Army Lauds FCS Advanced Collaborative Environment," *Defense Daily*, September 9, 2004.

¹⁴¹Interview data.

Complementary Program Interfaces Experienced and Created Technical and Other Challenges

FCS relied on many external programs for technologies to meet its requirements. Through various agreements between the FCS program and other agencies controlling complementary programs, relationships were built to bring essential technologies and systems into FCS and ensure that FCS equipment was able to integrate into existing systems either in development or available at the time. The implementation of formal Interface Control Documents (ICDs)¹⁴² was an attempt to align FCS with outside programs' cost, schedule, and performance.

ICDs are written to control the interactions between elements of a system in a beneficial way. For example, FCS field support equipment needed to connect with MGVTronics to diagnose faults. The characteristics of that connection, e.g., size, shape, impedance, power, and electronic format of exchanged information, had to be compatible with the vetric boxes. Such compatibility would have been controlled by an internal ICD because the support equipment and the MGVTronics boxes were funded and controlled by the FCS program manager, and were therefore internal to the FCS program.

External ICDs were more difficult to manage. They had to be written to ensure beneficial interactions and compatibility between FCS and elements external to FCS, such as WIN-T and JTRS, complementary programs that had their own PMs and funding sources. For such programs, an ICD could be written only as a result of negotiation between the controlling parties. Funding was also necessary to support the work needed to satisfy the ICD.

Over the course of many years, the FCS program identified dozens and at times over a hundred complementary systems (the technical underpinnings of these systems are dealt with in Chapter Eight).¹⁴³ For example, the Army mandated FCS's use of WIN-T and JTRS, two of the most notable and highly visible external complementary systems to the program. As such, they are used here to illustrate the FCS program's external ICD challenge.

Essential Complementary Systems Were Developed Simultaneously with FCS

WIN-T and JTRS were concurrently developed with FCS. The SDDs for all three programs overlapped; Figure 6.10 depicts the overlap for FCS and WIN-T, in particular. So although in principle ICDs could have been written between FCS and WIN-T and between FCS and JTRS, the ICDs would have to have been dynamic. As long as

¹⁴²Department of Defense, Defense Acquisition University, *Defense Acquisition Guidebook*, Section 4.2.3.1.8.

¹⁴³Government Accountability Office, *Defense Acquisitions: Key Decisions to Be Made on Future Combat System*, Report to Congressional Committees, Washington, D.C.: Government Accountability Office, GAO-07-376, March 2007.

According to one senior program official, many of the MOAs developed to support interfacing were, in hindsight, not specific enough. The MOAs should have been more akin to statements of work, to include a program schedule.¹⁴⁵

Interactions Among Complementary Systems and FCS Were Hampered

The interface process was also undermined by restrictions placed on engineers. JTRS and FCS program managers refused to let their supporting engineers communicate to understand the status of each program, for fear that news on technical challenges and other shortfalls might be reported to external organizations. As a result, FCS engineers struggled for several years to understand the status of JTRS.¹⁴⁶

Perhaps even more important, the FCS, WIN-T, and JTRS programs confronted technical and other challenges that, over time, resulted in SDD schedules that lengthened considerably from those expected at Milestone B. Moreover, none of the programs had funds to spare beyond their own program needs. JTRS and WIN-T were to serve FCS, but also had many other Army users and did not need to satisfy FCS for their programs to continue. FCS needed WIN-T and JTRS but, according to program officials, did not have the funds it needed to support ICD implementation.¹⁴⁷ Without effective ICDs, FCS encountered serious interface problems. The JTRS radio link to FCS's small UGV and small UAV had limited range, falling significantly below the FCS requirement, for example.¹⁴⁸

Essential ICDs for Complementary Programs Were Not Created

Program senior leaders understood the risks of relying on complementary programs, yet a formal complementary programs management plan had not been completed at SDD kickoff.¹⁴⁹ According to a senior program official, complementary programs were also not considered in the initial LSI contract, and fewer than half of the required interfaces had been explored by 2009.¹⁵⁰ Program veterans we interviewed universally stated that funding needed to develop and implement ICDs was either insufficient or nonexistent.¹⁵¹ Regarding the essential JTRS and WIN-T programs, interface summits were initiated, but these efforts came far too late to salvage the interfacing process.¹⁵²

¹⁴⁵ Interview data.

¹⁴⁶ Interview data.

¹⁴⁷ Interview data.

¹⁴⁸ Interview data.

¹⁴⁹ Boeing Company, "Future Combat Systems (FCS) System Development and Demonstration (SDD) Phase Systems Engineering Management Plan (SEMP)," May 16, 2003, p. 21.

¹⁵⁰ Interview data.

¹⁵¹ Interview data.

¹⁵² Interview data.

The FCS program's reliance on key external programs for success was a necessary but risky proposition and unlike past experiences in both scope and importance. (Chapters Eight and Nine of this report provide additional technical details of how important those interfaces were.) How the FCS program interfaced with key external programs, in terms of roles, responsibilities, and authorities, remains an important area for Army consideration as efforts unfold to consider Army unit capabilities. Interface challenges contributed to the FCS program's risk, and likely would have created significant problems in future years.

Conclusions and Lessons

Conclusions

From the program management approaches described in this chapter, both positive and negative lessons and legacies for the Army emerge. It is difficult to point to any one failure in the management of the FCS program that contributed most strongly to its ultimate demise. There seems to be general agreement, however, that the Army aggressively pursued a revolutionary battlefield capability and used innovative, high-risk, and at times unconventional management approaches in its attempt to achieve its aims. Yet too, FCS built knowledge, now resident in its people, on what it means to network a force and develop a brigade capability from the bottom up.

Lessons

The list of lessons below reflect the Army's desire to build broad, SoS-like capabilities across the force and lessons they might include as those efforts unfold.

Large-scale integration and development projects require significant in-service integration and engineering capabilities. The use of an LSI in the early 2000s was supported by many government officials and outside organizations and was rational in its broad intent, though later restricted in its execution. The Army's need for significant engineering and integration capabilities to meet the ambitious goals was clear, and industry—at the time—was largely seen as the best choice. As the Army moves toward the future and continues its development of brigade capabilities, FCS has shown how difficult from a management standpoint that will be.

Building brigade-level capabilities can enhance the ability to integrate systems into larger formations. The general acquisition strategy to consider Army capabilities in terms of larger formations and at the SoS level of detail was largely seen as supportable throughout our discussion with program officials and outside experts.¹⁵³ Program officials we interviewed largely agreed that the trend toward networked capabilities

¹⁵³ For instance, the GAO determined that acquisition by formation, a holistic approach, was the right idea. See Francis, "Defense Acquisitions Future Combat Systems Challenges and Prospects for Success," 2005, p. 3.

will increasingly demand movement away from acquisition of platforms in isolation and toward a more sophisticated consideration of how the Army should integrate systems into existing and future formations. FCS was a large step in that direction for the Army, albeit one that failed due to an unrealistic understanding of enabling technology maturity and an overly ambitious schedule for a very complex program.

In the meantime, it is important to continue to foster thinking about the Army as a system of systems, but to downsize the scope of individual programs that support the aggregate whole. This can help reduce interdependencies among systems until more fundamental knowledge about the brigade as a system is known. Formally defining system-of-systems requirements in Army acquisition manuals will help ensure that the definition elucidates distinctions between other requirements for commonality, open systems standards, interface definitions, data interoperability, network connectivity, and component systems performance.¹⁵⁴ If SoS requirements cannot be meaningfully distinguished from other related requirements, then the term should be dropped. Also, we recommend that the Army engage in fundamental research on what SoS-level features can be realized with the limitations in network performance that has been learned from the FCS experience.

Allow ample time to build appropriate supportive organizational structure and authorities to support brigade-level capabilities. Large, all-encompassing acquisition programs are not in the Army's near- or even medium-term future. However, incremental designs and upgrades will proceed as necessary, and with the continuing desire for brigade-level capability considerations, the Army will still need to address how it forms and executes programs to meet those needs. The Army structures and authorities are still being built to reflect brigade- or SoS-level thinking. An important lesson for the Army is to account for the time to build such structures—it took roughly 18 months for the vast FCS enterprise to achieve what one official referred to as “steady state” operations—sharing a common language, and envisioning a similar destiny. Careful consideration of how authorities are vested in Army organizations is needed.

Upfront system engineering and architecting are critical. Only certain aspects of systems integration can be concurrent, and most steps are necessarily sequential. Every veteran of the FCS program agreed that more preparatory SE is needed for such a large, ambitious program. SoS engineering should have been much stronger early in the program, entailing calling upon a deeper collection of SE&A experts within the Army. The Army has an opportunity to do so in the future, pulling from the work accomplished in FCS, and building toward a coherent future. Current Army management should consider consistently enforcing DoD's revamped acquisition policies to

¹⁵⁴It should be noted that many efforts have been and still are working in this direction: see Office of the Deputy Under Secretary of Defense for Acquisition and Technology, Systems and Software Engineering, *Systems Engineering Guide for Systems of Systems*, Version 1.0, Washington, D.C.: ODUSD(A&T) SSE, 2008.

include the requirement for early system engineering and completion of a first preliminary design review before Milestone B.

Concurrent development of the system-of-systems can complicate acquisition. In hindsight, it is clear that pursuing a revolutionary acquisition that was vast in scope and reliant on key elements being conducted concurrently with immature technology was far too complex an undertaking for the Army and the LSI to manage. Compared to more traditional acquisition strategies, the SoS approach significantly increased both the complexity of the organizations needed to execute the FCS program and the technical challenges associated with system engineering, software engineering, and system integration. The program's initial, overly ambitious schedule (see Figure 6.1) was ultimately jettisoned in part due to early budget decrements, which hampered the planned synchronization of SoS component launches and schedule adherence. Remedies for the inherent difficulties in this unprecedented concurrency and aggressive schedule are likely not even available. Past, common recommendations to simply not start engineering and manufacturing development (EMD) without mature technologies hold true for the FCS experience.

Quality personnel in the services are essential to acquiring complex systems of systems. The LSI succeeded in bringing industry leaders and their top talent to the FCS program, and the Army generally managed to recruit the best talent from its service and from the wider DoD acquisition community as well. Even so, the personnel "bench" was not deep, particularly on the government side, for such an ambitious undertaking. Key areas were developed in real time, including the significant capabilities built on the Army side to perform network analysis and SoS engineering. The government was particularly short on technical experts, and repeated changes to the FCS program diverted some of their efforts. The government's general shortage of acquisition talent remains to this day.¹⁵⁵

Past RAND research has recommended that the government use pay for performance as well as individual and group incentives, to attract and maintain technical talent.¹⁵⁶ Indeed, the 2009 Weapon Systems Acquisition Reform Act (Section 301) directs the Secretary of Defense to establish award programs for acquisition performance by individuals and groups, both civilian and military.¹⁵⁷ This development may facilitate the ability of ASA(ALT) to create incentive programs designed to attract technical personnel to support future acquisition efforts.

¹⁵⁵In 2011 the GAO reviewed 44 major defense acquisition programs and determined that just 23 were able to fill all authorized positions: Senior GAO official, remarks at the RAND Corporation, Arlington, Va., September 8, 2011.

¹⁵⁶See Beth J. Asch, "The Economic Complexities of Incentive Reforms," in Robert Klitgaard and Paul C. Light (eds.), *High-Performance Government: Structure, Leadership, and Incentives*, Santa Monica, Calif.: RAND Corporation, 2005.

¹⁵⁷David J. Berteau, Joachim Hofbauer, and Stephanie Sanok, *Implementation of the Weapon Systems Acquisition Reform Act of 2009*, Washington, D.C.: Center for Strategic and International Studies, May 2010, p. 12.

A strong acquisition capability will enable the service to assess industry performance in complex programs. The Army intended to undertake a “new paradigm” in its FCS acquisition strategy—an unprecedented partnership between industry and government was deemed necessary to bring the best talent to the program and to execute its aggressive schedule. However, this objective was never fully accomplished. The new paradigm was hampered by distrust, evolving roles and responsibilities, and general uncertainty on what to expect from each partner. These problems caused communication issues within the structures, and opened potential gaps in the Army’s ability to monitor and effectively manage progress. In response, ASA(ALT) should ensure that any future attempt to establish a partnership-type arrangement with industry requires that the Army maintain a strong internal capability to assess the performance of the commercial firms it engages for the purpose.

Integration organizations allow the enforcement of SoS discipline and can curb parochial branch influences. Many organizational lessons can be pulled from the FCS experience based on the successes and problems encountered. The scope of the FCS program, in terms of the systems and network it represented, mirrored many of the organizations existing in the Army—aviation, ground combat systems, artillery, and the like. In addition, the FCS program had integrating elements to help facilitate tradeoffs. The entrenched communities in the larger Army were also evident in the FCS program, as challenges arose in enforcing SoS-level thinking on the community and in communicating difficult problems through the chains of command. The philosophy behind the FCS program—that SoS-level integration would develop through complex interactions at multiple command levels—was a good start to a very difficult and complex problem.

SoS-level development will entail more significant decisions than the Army has had to make among acquisition programs in recent times. True SoS-level development will entail acquisition leaders’ ability to enforce “SoS discipline”—essentially putting the SoS above individual programs and systems, which was something that had not yet been fully realized in the FCS program. Forcing these difficult trades through appropriate structures, authorities, and top-level support, and creating the atmospheric for such a cultural change, will be necessary should the Army continue to think in terms of brigade-level capabilities.

Looking to the future, we suggest that the Army socialize the SoS concept early and ensure the necessary cultural shift for SoS development to work. It is important to encourage professional inquiry and communication up and down the chain of command. Managers should begin to think of ways to facilitate new means of communicating difficult problems and tradeoffs among constituent systems, as senior leaders need to be informed of the serious issues faced by lower levels. More specifically, appropriate SoS-level organizational structures (with authorities, roles, and responsibilities) should be instituted within the ASA(ALT) and requirements communities to facilitate SoS discipline consistent with future plans for SoS-level development.

Top-level organizations can ensure that senior leaders get involved in important decisions. Various top-level organizations—both standing, like the One Team Council and FCS Board of Directors, and ad hoc, like the FCS Team One—provided needed senior leader involvement in important decisions. Despite early concerns about the efficiency of those organizations, many thought they served useful roles during FCS and encouraged ownership and buy-in from across the Army. These types of organizations provide some lessons for future integration within the Army. Specific to the near future, we recommend that ASA(ALT) evaluate the potential use of FCS OTC- and BoD-like structures in future complex acquisition programs. Additionally, ASA(ALT) may wish to examine the FCS Team One¹⁵⁸ experience for SoS integration lessons learned and evaluate its organizational construct to consider the use of Team One-type bodies in future, complex acquisition programs.

Oversight and independent review by technically qualified personnel can provide crucial assessments of performance and risk. The Army's program management strategy included enhanced oversight mechanisms for OSD authorities. However, despite the OSD oversight opportunities touted at the beginning of FCS, the GAO found that OSD failed to exercise adequate oversight until late in the program.¹⁵⁹ The FCS program also employed various independent review teams in an attempt to get objective assessments of its performance and risks. Yet program officials thought that, in the end, the review teams too often lacked the expertise needed to make sound judgments, lacked objectivity due to conflicts of interest (i.e., many team members had worked on or otherwise maintained a relationship with the FCS program), and/or lacked the necessary stature needed to influence the program.¹⁶⁰ The 2009 Weapon Systems Acquisition Reform Act may result in enhanced capabilities for OSD oversight of Army and other service acquisition programs. However, an expansion of roles should also be explored to include Independent Review Teams (IRTs) in program management reviews and nonadvocacy reviews. The ASA(ALT) should consider evaluating approaches to the establishment of truly independent review teams that can provide objective assessments of weapon acquisition cost, schedule, technical performance, and risk.

Further, it is important to evaluate the sufficiency of IRTs to meet review needs in large acquisition programs and devise alternative methods for review. The DCMA lead was maintained at the highest level in the LSI structure. It developed an innovative and unprecedented approach to supporting the Army Program Management Office. The DCMA lead collected contract performance data from CMOs embedded at FCS contractor locations, managed and aggregated the reported data, and supplied

¹⁵⁸ There were many other groups, such as the "Program Working Group," that convened regularly to review risk mitigation plans and key decision points, which provided value and held additional lessons for the Army.

¹⁵⁹ Francis, "Defense Acquisitions Future Combat Systems Challenges and Prospects for Success," 2005, p. 4.

¹⁶⁰ Interview data.

it to the Army PM for review. The process established efficiencies while also affording the DCMA detailed insight into contractor performance across the United States. ASA(ALT) might consider a DCMA PIO-type organization to manage CMO contract performance reporting in support of the Army PMO for future, ACAT 1-level programs that involve multiple contractors.

Service visibility into and influence over subcontracting activities can foster competition and ensure commonality across platforms. The LSI proved adept at rapidly competing and executing subcontracts for major SoS components, and the program achieved a diverse supply base. Moreover, the government's co-leadership of IPTs enabled it to play a role in the selection of subcontractors for the FCS program and the Army could veto LSI source selections. The GAO has stated that the government's visibility into lower tiers of the LSI structure also enabled it to promote competition among lower-level suppliers and "ensure commonality of key subsystems across FCS platforms."¹⁶¹

While the effectiveness has not empirically or unequivocally been shown, the possibility for problems is opened with increased government involvement in subcontractor choices such as being put into a position of responsibility should problems at lower tiers arise. In any case, this relationship—seen as successful in the FCS case—should be considered for future programs if adequate data about the efficacy can be found.

EVMS and DOORS were employed to support FCS program management, but in the end they were not used effectively and failed to provide essential performance information to program managers in a timely fashion. While no large-scale acquisition programs like FCS are currently envisioned within the Army, future integration efforts might learn from those challenges and new techniques and capabilities should be built in advance. In the near future, ASA(ALT) should explore the possibility of a program-wide EVMS system that can be used for large-scale and/or complex acquisition programs. ASA(ALT) should also query the industry to determine whether suitable earned value systems are already in place in the private sector. ASA(ALT) should then explore new methods for identifying cross-requirement interdependencies, and common data dictionaries.

Consideration of and coordination with complementary programs can identify problems and enable mitigation strategies. Among the numerous program management difficulties experienced in the FCS program, a significant one was the extensive number of complementary programs. All were critical to the overall system of systems, particularly the network. Detailed systems engineering-based Interface Control Documents are much more difficult than specifying systems and subsystems that are under the control of the Program Manager. FCS was ambitious in its attempt to build brigade-level capabilities and thus necessarily would affect and be affected by programs from across the Army and other services. The articulation of

¹⁶¹ Francis, "Defense Acquisitions Future Combat Systems Challenges and Prospects for Success," 2005, p. 3.

complementary programs—numbering over a hundred at times during FCS—was not well founded on fundamental systems theory, but was widely seen as a necessary step in building to brigade-level requirements. Program senior leaders understood the risks of relying on complementary programs, yet a formal complementary programs management plan had not been completed at SDD kickoff.¹⁶² According to a senior program official, complementary programs were also not considered in the initial LSI contract, and fewer than half of the required interfaces had been explored by 2009.¹⁶³ Program veterans we interviewed universally stated that the funding needed to develop and implement ICDs was either insufficient or nonexistent.¹⁶⁴ Regarding the essential JTRS and WIN-T programs, interface summits were initiated, but these efforts came far too late to salvage the interfacing process.¹⁶⁵ Indeed, for a period of several years, engineers on these two programs were restricted from even communicating with their colleagues on the FCS program, as JTRS and WIN-T managers were concerned about reports of technical challenges being shared with personnel outside of their programs.¹⁶⁶

To this end, ASA(ALT) should develop policies and guidelines for how individual programs should:

- Anticipate the need for complementary programs and plan for their utilization.
- Plan early for coordination of interface specifications.
- Ensure that related MOAs or other instruments are specific enough to drive a successful interface process, to include an agreed schedule for completion and budget.

ASA(ALT) should also develop guidelines and policies for how programs should plan budgets for interface management between systems and their complements. In addition, ASA(ALT) might also engage in developing fundamental definitions, concepts, and risk-mitigation methods for SoS-level dependencies—both functional and data-interoperability—within a brigade.

¹⁶²Boeing Company, “Future Combat Systems (FCS) System Development and Demonstration (SDD) Phase Systems Engineering Management Plan (SEMP),” May 16, 2003, p. 21.

¹⁶³Interview data.

¹⁶⁴Interview data.

¹⁶⁵Interview data.

¹⁶⁶Interview data.

Contracts

This chapter discusses the way in which FCS contracting managers needed to modify traditional measures and procedures to meet specific FCS demands, and how the modifications themselves sometimes fostered program instability. It discusses, first, the contracts in the design concepts phase and the flexibility that was required at that point in the program. It then turns to the contract issues in the concept and technology development phases and the issues with the management structure. Finally, it describes the incentive structure in the Systems Development and Demonstration phase and the effectiveness of the incentives.

When the FCS program was initiated in DARPA, the program manager was primarily interested in developing innovative concepts and technology, as well as leveraging industry investment in the program. The different contracting strategies employed through the various phases of the FCS program undoubtedly reflect the different goals and changing nature of the program over time.

Contracts in the FCS Design Concepts Phase Were Marked by the Flexibility That the New Program Called For

While progenitor FCS activities had been taking place for some time, the program really formed in October 1999 following General Shinseki's vision speech. That event marked the start of a series of rapidly ensuing activities, including planning for a January 2000 Industry Day, the drafting of a memorandum of agreement between the Army and DARPA concerning FCS development, congressional coordination, and more formal budget planning. In addition, the DARPA FCS PM Office was writing and coordinating the initial FCS solicitation, which invited proposals for the FCS design concepts phase.¹

The solicitation noted that FCS partnering would be done with "Other Transaction Agreements"—throughout the program, including production, if authorized—

¹ DARPA, "Future Combat Systems Solicitation (Final)," January 31, 2000.

and that these would be awarded to several industry teams.² The solicitation also made clear that the industry teams would be expected to cost share in the development work. Proposers were strongly encouraged to be innovative in both their management approach and the performance characteristics of the systems and subsystems they were proposing. A key admonition to contractors as they developed responses to the solicitation was to “use a clean sheet of paper approach in order to design a highly responsive, strategic and tactical system.”³

Ultimately, four teams (see Table 3.2) were selected for Phase 1 agreements in May 2000, and each included multiple industry members.⁴ Each team was required to submit two designs, one defined largely by the government to include specific system types, the other their own SoS design.

The initial contracting plan was to select up to four teams to start the Concept Design Phase, then select two of those teams to prepare detailed designs of the best concept, and finally to select one team to build and test an FCS demonstrator. Ultimately, however, the program was restructured and the Army moved to directly identify a Lead Systems Integrator (LSI).⁵

Four agreements were awarded May 9, 2000. Table 7.1 identifies the team leaders and breaks out the initial agreement values.⁶ In all cases, the government contributed \$10 million. The industry teams determined how much they would contribute, and that value was reflected in the agreement for each team.⁷

² OTAs were designed to provide a contracting mechanism for research projects that were more commercial in structure and not encumbered by the restrictive requirements of the Federal Acquisition Regulation (FAR). The justifications for establishing the OTA centered around the concerns that small, innovative research organizations had neither the resources nor the inclination to comply with the burdens they perceived inherent in FAR-based contracting. When first introduced to the DoD in 1989, only DARPA was authorized to use the OTA. Amendments in the early 1990s authorized use of the OTA more broadly to the services and allowed its use in contracts for “prototypes.” See L. Elaine Halchin, *Other Transaction (OT) Authority*, Congressional Research Service, November 25, 2008.

³ Department of Defense, Office of the Assistant Secretary of Defense (Public Affairs), “DARPA and Army Select Contractors for Future Combat Systems Programs,” DoD News Release, May 9, 2000.

⁴ Department of Defense, Office of the Assistant Secretary of Defense (Public Affairs), “DARPA and Army Select Contractors for Future Combat Systems Programs,” 2000.

⁵ Chris Strohm, “Army Unveils Next Phase of Future Combat Systems Program,” *Inside the Army*, November 12, 2001. The restructuring of the program at this point is discussed in more detail elsewhere in this report.

⁶ See agreement numbers MDA972-00-9-0001 (Boeing); MDA972-00-9-0002 (SAIC); MDA972-00-9-0003 (FoCuS); and MDA972-00-9-0004 (Gladiator).

⁷ Subsequently each team received two plus-ups, the first \$3 million. In September 2001, the Army decided to restructure and accelerate the FCS program and provided \$2 million in additional funds to each in order to allow Phase 1 completion by February 2002, rather than in May, as originally planned. (Team FoCuS may be an exception. Either it did not receive the second plus-up or we do not have a copy of the amendment that added the money).

Table 7.1
Initial Concept Design Phase Agreement Funding

Team	Contractor Cost Share	Government Amount	Total Contract Value
Boeing (Phantom Works)	\$13.3M	\$10M	\$23.3M
SAIC	\$2.8M	\$10M	\$12.8M
Team FoCuS Vision (GDLS, Raytheon)	\$4.0M	\$10M	\$14.0M
Team Gladiator (TRW, LM, CSC, CMU, Battelle)	\$5.5M	\$10M	\$15.5M

Scopes of Initial Agreements Were Similar, but Additional Statements Varied

The scopes of the initial agreements were very similar. Each included the following:⁸

- Develop system-of-systems concept solutions for key areas of mobility, lethality, survivability, deployability, and supportability.
- Develop at least two force concepts with recommended doctrine and tactics, techniques, and procedures along with associated tradeoff-based rationale assessments.
- Quantify the performance of the initial force and system(s) concepts and develop data, including the rationale and sources of data pertaining to their force and system(s) concepts.
- Identify the technologies, missions, and tasks necessary to conduct the range of combat operations, associated tradeoffs, opportunities for preplanned product improvement, technical and schedule risks, interfaces with other organizational elements, and anticipated key component/system performance parameters.

While these similarities maintained some consistency between the four teams, further statements maintained their differences. For example, some teams explicitly mentioned simulation-based acquisition approaches, some mentioned mission areas of emphasis (i.e., mobility, indirect fires, support, lethality, etc.). Three of the four mentioned the development and use of an Integrated Data Environment (IDE) to be shared with the government. Since the ultimate course that the FCS program followed was very different from what was envisioned during the design concept phase, it is unclear whether these varying approaches to scoping this initial work had, or would have had, any impact on the FCS program.

All four agreements had a 24-month estimated period of performance. Management structures specified in the agreements varied somewhat depending on the structure of the team, and the degree to which government personnel would be included. The payable milestone schedules tended to be similar at the top level, but different in their specifics. All mentioned concept development activities, tradeoff analyses, and

⁸ See agreement numbers MDA972-00-9-0001 (Boeing); MDA972-00-9-0002 (SAIC); MDA972-00-9-0003 (FoCuS); and MDA972-00-9-0004 (Gladiator).

technology investment reviews, often laid out iteratively (i.e., initial concept development followed by refinement based on the results of the tradeoff studies). Some milestones were administrative (hold kickoff meeting) while some were functional or substantive (technology survey and assessment). All four agreements gave the government “a nonexclusive, nontransferable, irrevocable, paid-up license to practice, or have practiced on behalf of the Government, throughout the world.”

There were other differences among the four design concept phase agreements as well. For example, in the section on data rights, the SAIC agreement incorporates the Defense Federal Acquisition Regulations Supplement (DFARS) clauses that apply to the subject, whereas the other three agreements disregard the FAR and the DFARS and use their own language. The SAIC and Team FoCuS Vision agreements used the payable milestone list as the deliverables list. The Boeing and Gladiator teams specified deliverable lists that were different from their payable milestone lists and different from each other. The Boeing and FoCuS Vision agreements included an article on subcontractors, specifying the use of best commercial practices and a waiver from the need for competitive bids; Team Gladiator and SAIC had no such article.

These similarities and differences in the initial agreements, and in the amendments to each agreement, illustrate the flexibility and ability to tailor processes and content inherent under OTA. The use of OTA in the design concept phase was clearly warranted, given the exploratory nature of the work.

Contracts in the FCS Concept and Technology Development Phase Were Marked by a Contradictory Management Structure

The Army Chief of Staff, General Eric Shinseki, wanted the program to transition from DARPA to the Army while he was still the Chief. This would require that the FCS program transition from an exploratory DARPA technology program to an official acquisition program of record. It was also important that the program transition a successful acquisition milestone event before Shinseki’s departure from CSA in the spring of 2003.⁹ As noted in Chapter Three, the FCS program was, in fact, restructured in September 2001 to accelerate the program and accommodate a Milestone B decision in May or June of 2003. DARPA retained day-to-day management authority, but the Army took on a much larger role. The Army set up its own program office, headed by Brigadier General Donald Schenk (previously the Stryker PM), and TRADOC took over the leading role in developing the FCS concept of operations and requirements development.

⁹ Neither General Shinseki nor any official Army statement declared a specific intent to manage these significant transition events to occur during Shinseki’s term as Chief of Staff. That intent, however, was expressed as recollection or opinion during interviews with personnel knowledgeable of events at the time.

Between September 2001 and January 2002 the DARPA PM developed a new program solicitation to institute the changes in program structure and schedule.¹⁰ Importantly, the solicitation announced the competition for an LSI to manage the FCS program through Milestone B and full program transition to the Army. The LSI would be responsible for the C4ISR architecture, and would have total system integration responsibility. In practice, this meant that the LSI was to be responsible for all cost-performance tradeoffs and the decomposition of desired capabilities and approved requirements into system specifications. As discussed elsewhere, this represented a major change from traditional program management approaches. However, though the government's intent was to not interfere with LSI processes, it reserved "the right to participate as a full partner in all program decisions," and the solicitation further declared that the LSI would partner with the government in an Integrated Product Team (IPT) structure to manage and execute all aspects of the program.

This somewhat contradictory management structure remained an important aspect of the FCS program until the end. While it was intended to create a collaborative teaming arrangement between the LSI and the government, it also had consequences in terms of managing contractual incentives.

This new solicitation also contained the first mention of Phase 1 as the Concept and Technology Development (CTD) phase of the FCS program, thus acknowledging that it had become a Major Defense Acquisition Program (MDAP) under the DoD 5000 series of directives and instructions. A System Development and Demonstration (SDD) phase was to be an option in the CTD OTA.

Industry Teams Needed to Negotiate and Renegotiate Partnering

The solicitation encouraged the four existing teams to continue to team up, but did not require that the team composition remain the same and, in fact, the teams reorganized for the new competition. Three industry teams submitted proposals: (1) General Dynamics Land Systems, Raytheon, United Defense, Northrop Grumman, and ITT Industries, (2) Boeing and Science Applications International Corp., and (3) Lockheed Martin and TRW Inc.¹¹ Three criteria were to be used in proposal evaluation:¹²

- Statement of Required Capability (SoRC) compliance over time (most important)
- management approach
- cost.

¹⁰ DARPA PS 02-07.

¹¹ Chris Strohm, "Army, Industry Prepare to Move into Next Phase of FCS Program," *Inside the Army*, January 12, 2002.

¹² DARPA PS 02-07.

Government funding of \$154 million was identified in the solicitation for the FCS CTD phase (\$40 million in FY02 and \$114 million in FY03), and the SDD phase was anticipated (at that time) to be funded at \$4B.¹³ These were, by historical standards, quite small amounts relative to the scope of the program.¹⁴ Ultimately, when FCS SDD was definitized in more detail, it was budgeted at greater than \$14B.

The agreement for the CTD phase was awarded March 14, 2002, to the Boeing/SAIC team.¹⁵ The total value of the agreement was \$240 million over an 18-month period of performance. The government (DARPA and the Army) would provide \$154 million (64 percent), while the Boeing/SAIC team was to provide the remaining \$86 million (36 percent). All of the industry contribution was to be in the form of Independent Research and Development (IRAD) of several different types:¹⁶

- IRAD/Internal Application Development—\$7 million
- common benefit IRAD—\$27 million
- program-related IRAD—\$52 million.

The CTD agreement was fairly short—about 40 pages—including some of the attachments. It defined the roles, responsibilities, and relationships between the government and industry participants. Some of the key elements of the agreement included:

- The LSI was given total system integration responsibility for designing, developing, producing, fielding, and supporting the FCS system of systems.

¹³ There were four significant changes in scope to the CTD Agreement. Amendment 11 added \$36 million to the program's Manned Ground Vehicle effort and identified General Dynamics and United Defense as the sole possible sources. Amendment 12 (\$2 million) established an Integrated Design Team (IDT) for Networked Fires. Amendment 18 (\$29 million) funded the Networked Fires Risk Mitigation Effort, which is associated with the "make" decision to allow the LSI to develop the System of Systems Common Operating Environment (SoSCOE), the overarching communications and data exchange architecture within which FCS sensors and shooters operate. Amendment 32 (\$1.5 million) added an Army analysis effort related to the Distributed Common Ground System—Army (DCGS-A). Total government funding by the end of CTD was \$221 million.

¹⁴ By way of comparison, nearly \$4B in then-year dollars had already been invested in the Crusader artillery system's demonstration/validation phase of development (equivalent to CTD). The amount of \$1.9B was planned for the Crusader's engineering development phase (equivalent to SDD). (Crusader costs and cost estimates were derived from multiple documents: Department of the Army, Office of the Secretary of the Army (Financial Management and Comptroller), "Descriptive Summaries of the Research, Development, Test and Evaluation Army Appropriation, Budget Activities 4 and 5," *Supporting Data for the FY 1999–FY 2004 Budget Estimates*; and Office of the Under Secretary of Defense (Comptroller), *National Defense Budget Estimates for FY 2002*, Washington, D.C., August 2001.) The Crusader program consisted of just two vehicles, a 155mm self-propelled artillery cannon and a supporting resupply vehicle. The Crusader program was cancelled in May 2002 to free up funding for the "transformational" programs, such as FCS.

¹⁵ Agreement Between the Boeing Company and DARPA Concerning Future Combat Systems (FCS) Concept and Technology Development (CTD) Phase, MDA972-02-9-0005, March 14, 2002.

¹⁶ A portion of a defense contractor's IRAD investments is reimbursed by the government.

- The LSI had authority to use “best commercial practices” in managing the program, including assembling the industry team and managing subcontractor competitions. Most “passthrough” regulations typical in FAR-based contracting procedures were waived.
- The LSI had the responsibility to support the government through a successful Milestone B decision, to be held within 30 days of a planned Army System Acquisition Review Council (ASARC).
- The LSI would conduct a go/no-go program review no later than September 25, 2002.
- The LSI had a full range of program management and substantive responsibilities, including requirements determination (in support of TRADOC), analysis of alternatives, development of program documentation supporting the ASARC and Milestone B milestones, concept and technology demonstrations to ensure maturity, and developing various levels of the program’s architectures (system of systems, C4ISR, and platform).

Importantly, the agreement also began to establish the close relationship between the government and LSI that was to continue throughout the program.¹⁷ The IPT structure that was established in the agreement was to become central to the close relationship between the government and the LSI. The agreement stated that “The FCS program will be managed and led through an overarching Program Management (PM) IPT, co-chaired by both the PM Objective Force and PM LSI.”¹⁸ Below the overarching IPT were supporting IPTs that were LSI-led and government co-chaired (or vice versa), sub-IPTs, and working groups. The agreement further specified oversight responsibilities for the government IPT members.¹⁹ But the government members of the IPTs were also encouraged to go beyond oversight by the agreement and to express their views and interests. Furthermore, it was intended that IPT actions would require consensus between the LSI and government IPT members and that lacking consensus, issues would be elevated up the IPT chain.²⁰ While the IPT structure was meant to foster partnership, enhance flexibility, and result in rapid issue resolution, it also had the effect of enmeshing the government at all levels of the program, essentially dilut-

¹⁷ MDA972-02-9-0005, Article I, Section A, Paragraph 1:

The Boeing Company, as the Lead Systems Integrator (LSI), and its industry teammate, Science Applications International Corporation (SAIC) shares with DARPA and the United States Army a common vision for the Future Combat Systems (FCS) that will serve as the material foundation for the Objective Force. We are entering into a comprehensive partnership with the Government to provide new technologies, capabilities and techniques for the Army to fulfill an expanding and evolving set of Army missions for the 21st century.

¹⁸ MDA972-02-9-0005, 2002, Article IV, Section A, Paragraph 2.

¹⁹ MDA972-02-9-0005, 2002, Article IV, Section C, Paragraph 3.

²⁰ MDA972-02-9-0005, 2002, Article IV, Section C, Paragraph 4.

ing LSI authority and its responsibility for programmatic actions and decisions. Conversely, the government's oversight role is diminished to the extent that it participates in the actions and decisions of the IPTs.

The deliverables called out by the FCS CTD OTA were entirely paper, mostly in the form of plans (e.g., risk plans, M&S plans, software development plans, etc.), or the results of simulation exercises.²¹ Though various demonstrations were identified in the statement of objectives, no technology demonstrations or experiments were identified as CTD phase deliverables. Interestingly, the OTA does not mention or refer back to work performed under the original Design Concept phase agreements.

The Agreement Made Some Distinctions Between DARPA and Army Responsibilities

TRADOC was given requirements determination authority. The AAE was given veto power over LSI source-selection decisions. And though it was given responsibility for contractor performance reviews and managed the program on a day-to-day basis, DARPA appeared to have limited authority to direct program activities or provide overall direction.

Unlike the agreements in the Concept Design Phase, the FCS CTD agreement included a performance payment incentive: 85 percent of allowable incurred costs invoiced monthly to DARPA would be paid to the LSI.²² The remaining 15 percent was withheld as an incentive fee, payable at specific milestones after a determination of contractor performance. These milestones were, however, administrative and included a series of In-Process Reviews (IPRs), the April 2003 ASARC, and the Defense Acquisition Board (DAB) Milestone B, which was to occur approximately 30 days after the ASARC. The DARPA PM was responsible for these assessments using a specified set of cost, schedule, management, and system engineering criteria. The criterion within these categories was stated broadly, with no firm metrics or thresholds stated within the agreement, though the agreement did state that "The Parties may elect to negotiate specific criteria for each Milestone Event prior to the start of each Milestone Event

²¹ The deliverables list from the agreement contains 22 separate items (labeled C001—C022) due at Interim Program Reviews (IPRs) or similar program status reviews. All of these are documents of one form or another such as plans, specifications, or reports on particular issues (i.e., industry and technology base capability). All are the kinds of documents needed to plan for and manage a complex weapon system development program, such as a risk management plan (C015), integrated master plan (C007), C4ISR performance specifications (C012), interface requirements document (C004), competitive process plan (C014), requirements compliance matrix (C021), and software development plan (C018). Of special note is the first item, milestone documentation (C001), which is defined as "all documentation for ASARC and DAB reviews." The implication is that the LSI had responsibility and accountability for preparation of the documentation required by DoD acquisition regulations for milestone approval, a function normally held by the government program office.

²² It is actually somewhat less, since the funding ratio (64 percent government/36 percent industry) was also used as a billing ratio.

evaluation period.”²³ It is unclear whether this ever occurred. To the extent that less than 100 percent of the available incentive payment was awarded in any given period, the remaining funds would become part of the incentive pool for the next review. Over the course of the agreement, 100 percent of the incentive fee was paid.²⁴ Since the CTD OTA included a rating scheme that stated that 100 percent payout of incentive fee was for “excellent” performance, the government must have evaluated the LSI’s performance during CTD as excellent.

Systems Development and Demonstration Phase, Program Definitization Agreement Defined Incentives and Fee Layout

On May 17, 2003, the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD(AT&L)) approved FCS for entry into the Systems Development and Demonstration (SDD) phase. In anticipation of entering SDD, the Army planned to exercise its CTD OTA option to continue with the Boeing/SAIC team as the LSI for the FCS program during SDD. A new OTA was prepared and signed on May 23, 2003 (effective May 30, 2003) that defined the agreement between the Army and the LSI for the period between SDD initiation and the definitization of the SDD program (approximately six months).²⁵ This phase of the work was initially valued at \$190 million (\$130 million in FY03 and \$60 million in FY04), which, at the time, was deemed insufficient to meet the announced schedule. At the time of signing, the FCS program anticipated initial operational capability (IOC) in 2010 for an Increment 1 FCS-equipped maneuver battalion and full operational capability (FOC) in 2012 for an FCS-equipped Objective Force Unit of Action (now called a Brigade Combat Team).²⁶ It is important to point out that this agreement marked the point in time when the Army officially became contractually responsible for the FCS program.

²³ MDA972-02-9-0005, Article X, Section C, Paragraph 3.

²⁴ Amendment 36, the last amendment to the CTD agreement, notes “Total Estimated Government Funding of the CTD Phase Agreement: \$221,276,379” and identifies “Total Government Funds Obligated to Date: \$221,276,379,” indicating that all available government funding, including incentive fee, had been obligated.

²⁵ “Agreement Between the Boeing Company and the U.S. Army Tank-automotive Armament Command, Concerning Future Combat System (FCS) System Design and Development (SDD),” Agreement No. DAAE07-03-9-F001, May 30, 2003.

²⁶ DAAE07-03-9-F001, 2003.

But the real focus of the Program Definitization Other Transaction Agreement (PDOTA) was on getting the SDD agreement definitized.²⁷ As will be described below, the incentives were structured to motivate the LSI to do this.

Use of an OTA was justified by noting that the FCS program intended to rely on innovative business practices that would be infeasible with a FAR-based contract and would be using nontraditional defense contractors in significant roles. However, the OTA was structured in a manner that was generally similar to a cost-reimbursable FAR-based contract. Moreover, it is not clear what business practices the LSI anticipated and that would have been unavailable to it under a FAR-based contract. As for using nontraditional defense contractors, the PDOTA was with the LSI—a traditional defense contractor—and the FAR provides means for managing nontraditional subcontractors.²⁸ In fact, the OTA still required Boeing to identify when “normal flowdown” would harm FCS program goals and ask the government for relief in those cases.²⁹ Generally, the use of the OTA to manage the FCS program appears to be more a matter of convenience, history, and attitude: convenience from the standpoint of being able to do things differently if more contracting options happened to be required; history from having evolved from a DARPA program that utilized the OTA contracting form; and attitude from the standpoint that the people involved in the FCS program were enthused with the notion of doing something that would transform the Army, and so needed to break from the traditional way of contracting and use something more appropriate to the nature of the program.

The potential incentive fee for the Program Definitization period was 13 percent. This was divided into a 5.2 percent base fee to be paid as a percentage of the costs and a 7.8 percent incentive fee to reward the accomplishment of five definitization activities. These are essentially the deliverables for the Program Definitization phase and listed in Table 7.2.

The first four fee activities earned fee upon completion of the activity. The final activity (Definitization) included a penalty clause for lateness. If the Definitized Agreement was not delivered within 210 days of the signing of the PDOTA, the LSI would lose \$822,852 of Activity 5’s incentive fee (5.6 percent of total available fee) and an additional \$822,852 every 30 days thereafter. In any event, the Definitized Agreement was delivered early.

²⁷ DAAE07-03-9-F001, 2003, Article I, Section B, Paragraph 8 of the PDOTA notes that

The modification that definitizes the ceiling priced Agreement is planned to be a totally superseding modification for the entire FCS SDD program, incorporating those fixed portions of the business arrangement reflected in this Article for the definitization period.

²⁸ For example, while the PDOTA required subcontractors to comply with federal cost principles and the FAR prohibits “excessive passthrough charges,” the FAR also offers various methods for managing subcontractor price issues. FAR Part 15.403.

²⁹ DAAE07-03-9-F001, Article VIII, Section B, Paragraph 1.

Table 7.2
Fee Activities During the Program Definitization Phase of SDD

Fee Activity	Definition	% of Available Incentive Fee
Technical	The FCS Increment 1 specification update aligned and reconciled with the ORD approved by the JROC in April 2003	11.1%
Software	A test bench demonstration of the Net Fires use case utilizing SoS COE Build 0	11.1%
Subcontracts	Resolution of 100% of the competitive subcontracts and definitization of 85%	22.2%
Manpower	Agreement between LSI and government on LSI manpower	22.2%
Definitization of Agreement	Completion of the final definitive agreement for SDD, including the fee arrangements for the balance of the SDD program	33.3%

SOURCE: DAAE07-03-9-F001, 2003, Article I, Section B, Paragraph 5.d.

In discussion of fee, the PDOTA expressed a commitment to providing the LSI the maximum available fee, citing the complexities and the risks involved. There was certainly programmatic risk involved, but it does not appear that the LSI shared those risks to the same degree as the government, particularly going forward.³⁰ The SDD agreement, in pre-definitized and definitized versions, was essentially a cost-reimbursable contract. Even in the event of early termination of the FCS program, the LSI would prepare a termination settlement proposal and all its costs, including earned fee, would be paid.³¹ This does not mean that the LSI did not necessarily merit the fee proposed, merely that citing LSI risk was unjustified. Instead, the difficulties and complexities involved in the accomplishment of the definitization activities could justify the payment of additional fee for those activities.

The PDOTA built upon and made more detailed the CTD IPT framework for structuring the relationship between the Army and the LSI. This framework was to exist for the duration of the entire SDD phase of FCS development. The framework included:

- The IPT structure for managing the program. This was similar to the structure introduced in CTD, though providing somewhat more detail.³²
- Instructions concerning “make/buy” decisions. The AAE had to approve all make/buy decisions at the system and subsystem level, and the PM FCS would approve such decisions at lower levels.³³

³⁰ As noted earlier in this chapter, Boeing invested some of its own resources in the Concepts Design (\$413.3 million) and Concept and Technology Development (\$86 million) phases. Much of this was IRAD funding, though, which is reimbursable.

³¹ The PDOTA incorporated FAR clause 52.24906 to cover termination procedures.

³² DAAE07-03-9-F001, Article IV, Section A, Paragraph 1, and Section D, Paragraphs 1–3.

³³ DAAE07-03-9-F001, Article VIII, Section A, Paragraphs 1–3.

- Development of the System of Systems Common Operating Environment (SoSCOE). Made Boeing's responsibility, but with conditions.³⁴
- Subcontractor competition and directed subcontracts. Continued the competitive process put in place during CTD, but granted the government the right to direct subcontracting actions.³⁵

Each of these clauses was continued in the definitized SDD agreement.

Systems Development and Demonstration Phase Definitized Other Transaction Agreement Defined Provisions Related to Performance, Schedule, Fees

In December 2003, Boeing and the FCS program office signed a definitized SDD OTA.³⁶ The total agreement value at the time of SDD definitization was about \$14.8B in then-year dollars (Table 7.3). The LSI function (Boeing plus SAIC) was valued at about 32 percent of the total, excluding fee.³⁷

For the most part, the definitized agreement left in place the programmatic structures that had already been established. The major impact of definitization was, therefore, the establishment of the fee structure to incentivize LSI performance. Though this

Table 7.3
FCS SDD OT Funding Breakout

Firm or Function	Value (\$MTY)
Software contingency	\$912
Fee (shared)	\$1,926
Ground Vehicles (directed)	\$4,137
Competitive subcontracts	\$1,744
SAIC LSI	\$1,129
Boeing LSI	\$3,661
Boeing "make"	\$1,271
Total	\$14,780

SOURCE: "Review of FCS Management Issues," IDA, August 17, 2004, Chart 5.

³⁴ DAAE07-03-9-F001, Article VIII, Section A, Paragraph 4.

³⁵ DAAE07-03-9-F001, Article VIII, Sections B and C.

³⁶ DAAE07-03-9-F001, P00063, December 10, 2003.

³⁷ Prior to the start of SDD, the Army approved Boeing's software "make" decision to provide the Distributed Information Management System (February–March 2003). The Army also directed contract awards to General Dynamics and United Defense for the MGVs (January 2003). Boeing's total share of the FCS contract at this point, including the "make" decision for SoSCOE, but excluding fee, is about 33 percent of the total.

was an OTA, the FCS SDD contract was structured like a standard cost, plus incentive fee (CPIF). In this case, total potential fee was 15 percent,³⁸ which was divided into a 10 percent fixed-fee portion and a 5 percent incentive fee portion. The incentive fee was further divided into three portions: 50 percent of the incentive fee was made available for incentivizing performance, 25 percent was made available to maintain schedule, and 25 percent was made available to encourage cost containment.³⁹

The schedule for evaluating and paying incentive fee was constructed around ten “fee events.” The fee events themselves reflected the overall program structure and were designed to incentivize the LSI to effectively move the FCS program through the various SDD steps, most importantly the significant DoD/Army milestones, such as the preliminary design review, critical design review, and Milestone C.⁴⁰

The contract itself specifies only very high-level criteria for determining incentive fee payout, instead referring to other program documents for the details and evaluation criteria. Each of the ten fee events were structured similarly:⁴¹

- **Performance.** Incentive fee is earned for successful completion of the event (usually defined as an engineering or capability maturity event) as defined in the Integrated Master Plan. The IMP contains “accomplishment criteria” and “completion criteria” for measuring overall success.
- **Cost.** The cost incentive had two parts. The first required an LSI commitment to restrain FCS cost with the development, implementation, and demonstration through examples of a life cycle cost containment plan (LCCCP). The second part required that the LSI-generated estimate of average unit procurement cost (AUPC) adhere to an agreed-upon “glide path.” In other words, the LSI-estimated AUPC for the FCS was expected to decline over time and as the design matured. The LSI’s estimated decrease was measured against a predetermined glide path of an expected or desired AUPC.
- **Schedule.** The schedule incentive was paid if the LSI successfully completed the fee event within 90 days of the time specified by the Acquisition Program Baseline (APB). In addition, the LSI was required to have updated the Integrated Master Schedule and IMP after the previous incentive event.

The dynamic nature of the FCS program was recognized in the definitized SDD OTA. A clause was included that required the government and LSI to reevaluate the incentive criteria for each incentive event two years prior to the scheduled occurrence

³⁸ Were this a cost plus fixed fee contract, the maximum allowable fee would have been 15 percent (10 U.S.C. 2306(d)).

³⁹ DAAE07-03-9-F001, P00063, Article VII, Section A.

⁴⁰ DAAE07-03-9-F001, P00063, Article VII, Section B, Paragraphs 5–7.

⁴¹ DAAE07-03-9-F001, P00063, Article VII, Section C.

of the event. If circumstances necessitated, the incentive requirements for that event were to be modified and incorporated into the contract no later than a year prior to the event's occurrence.⁴²

Systems Development and Demonstration Phase Restructured the FCS Contract to a Standard FAR-Based Contract

Within about a year of signing the definitized SDD OTA, questions about the FCS program began to be raised, particularly by Senator John McCain, then chairman of the Airland Subcommittee of the Senate Armed Services Committee.⁴³ In a March 31, 2005 letter to then Secretary of the Army Francis Harvey, McCain stated concern that the OTA was not subject to laws meant to protect the public trust, such as the Truth in Negotiations Act (TINA). Moreover, he noted that OTAs were meant to attract small technology-oriented companies to DoD work, not traditional defense contractors. Among the issues McCain questioned was why a program as large as the FCS needed to use an OTA rather than a FAR-based contract. Principal among his concerns was that an OTA may not have the same protections as a FAR-based contract in terms of preventing fraud. He also questioned the propriety of using an agreement instrument that was developed for smaller R&D contracts and to engage with contractors that would not normally work with the DoD.⁴⁴

⁴² DAAE07-03-9-F001, P00063, Article VII, Section C, and Section B, Paragraph 4.

⁴³ It is worth noting that Senator McCain's interest in the FCS program began shortly after controversy concerning another Boeing deal, a potential Air Force contract for leased tanker aircraft, made the news. In that case, a number of organizations and individuals, including Senator McCain, questioned various aspects of the deal to lease tankers. Ultimately, the deal was quashed and allegations against a senior Air Force official and a Boeing executive resulted in their indictment and sentencing on ethics violations related to the tanker deal. Rebecca Leung, "Cashing in for Profit?" CBS News, February 11, 2009.

⁴⁴ Jen DiMascio, "McCain Questions Army Leaders About FCS Contracting Agreement," *Inside the Army*, March 21, 2004.

As noted elsewhere, the OTA was, in most ways, structured like a FAR-based CPIF contract. Neither the GAO nor the Institute for Defense Analyses expressed concern about the OTA in congressional testimony. In fact, Dr. David Graham, the Deputy Director of Strategy Forces and Resources Division at IDA, noted in response to a question from Senator McCain that

we had told the Army we thought they had sufficient visibility of costs and sufficient authority to control the contractor under the OTA to execute the program effectively. The OTA that was in use at that time, as I said, had a lot of FAR-like provisions put into it by the Army.

David Graham, Hearings Before the Committee on Armed Services, One Hundred Ninth Congress, Second Session on S.2766, March 1, 28, July 25, 2006.

Though the Army defended the use of the OTA,⁴⁵ it ultimately chose to restructure the FCS contract as a standard FAR-based R&D contract in 2005.⁴⁶ This restructuring resulted in two major changes concerning issues that had been raised in the discussions about the OTA but were in fact unrelated to the contract form.⁴⁷

The first concerned the fee structure. Under both contract forms, the maximum potential fee for the LSI was 15 percent of allowable program costs, but the composition of the fee changed. The OTA awarded Boeing a fixed fee of 10 percent of cost and the potential to earn an additional incentive fee of 5 percent. In the restructured, FAR-based contract the fixed fee was 7 percent, while the incentive fee was 8 percent. The split between the fixed and incentive percentage was not dependent on the contracting mechanism, but rather on the goals of the parties.⁴⁸ The practical difference, in terms of total incentive earned, between the two incentive structures was very small. Boeing earned the entire fee available prior to the 2009 program restructuring and downsizing. However, government personnel interviewed during this study consistently noted that the relationship between the LSI and the government changed with the incentive restructure. What was described as a “partnership” to develop the FCS under the OTA became more characteristic of a traditional contractor/government relationship. This meant, according to the people who described the change, less flexibility on the LSI’s part and stricter adherence to formal agreements and direction.

Another major contractual issue involved whether Boeing, as the LSI, could compete for system- and component-level FCS work; essentially as a subcontractor to itself. The OTA allowed for this in the specific instance of the SoSCOE. Even though

⁴⁵ Claude Bolton, “Hearings Before the Committee on Armed Services, One Hundred Ninth Congress, First Session on S.1042,” Part 4, AirLand, March 16, April 6, 14, 2005.

⁴⁶ William Matthews, “Unconventional Weapons Deal FCS Program Now Faces More Scrutiny in Standard Contract,” *Army Times*, April 25, 2005.

⁴⁷ During this same time frame (2004 through 2005), Senator McCain also raised the issue of fee-on-fee in his hearings on the FCS program, asking “does the LSI charge fee on fee from its subcontractors, and if so, why?” Fee-on-fee is the concept in which a prime contractor, or LSI in this case, earns fee (profit) on the fees charged by their subcontractors. This definition gives the impression that the prime contractor, or LSI, is earning additional fee for doing nothing. However, as Claude Bolton, then the Assistant Secretary of the Army (Acquisition, Logistics and Technology) noted,

Subcontractor fee is treated as costs to the LSI. This practice is in accordance with industry-wide accounting practices and Boeing’s approved disclosure statement. As is customary, and in line with industry standard, all prime/LSI contractors charge and receive fee for any agreed-to fee from immediate subcontractors.

Indeed, FAR Part 31.204 confirms that

Costs incurred as reimbursements or payments to a subcontractor under a cost-reimbursement, fixed-price incentive, or price redeterminable type subcontract of any tier above the first firm-fixed-price subcontract or fixed-price subcontract with economic price adjustment provisions are allowable to the extent that allowance is consistent with the appropriate subpart of this Part 31 applicable to the subcontract involved.

⁴⁸ Several interviewees suggested that the change to the incentive structure actually was the result of political pressure on the Army rather than a desire to realign incentives and program goals.

these opportunities for the LSI were very limited in the OTA, and the agreement provided specific restrictions,⁴⁹ such “inside” work was criticized as a conflict of interest. Critics noted that allowing the LSI to compete for non-SoS-level work meant that the LSI might not have the best interests of the FCS program in mind when selecting subcontractors. In the transition to a FAR-based contract, specific “conflict of interest” language was included that forbade the LSI from competing for any new non-SoS-level work, though work already contracted for was allowed to continue.⁵⁰ As with the fee breakout, the inclusion of this conflict-of-interest language was independent of the contract structure used. The OTA could have included such language and the FAR-based contract could have allowed such work and specified the conditions.

Incentive Effectiveness During the SDD Phase Was Mixed

Though the relative split between fixed and incentive fee changed when the FCS contract was restructured in 2005, the layout of the incentive fee remained the same. Both the OTA and the FAR-based contract allocated 50 percent of incentive fee to performance, 25 percent to cost management, and 25 percent to schedule maintenance. Moreover, the details that define the incentives were retained during the contract restructure. As a result, we assessed the effectiveness of the incentives from the FCS SDD OTA and FAR-based contract together.

Fee Schedule Was “Frontloaded”

As described above, the fee schedule for FCS SDD was organized around ten “fee events.” These were planned to continue as roughly annual events.⁵¹ Figure 7.1 displays the event schedule and the incentive fee associated with each one.

What is noticeable about the fee schedule is the frontloading. As the GAO noted, “By the time the Army completes the critical design review in 2011, the LSI could earn over 80 percent of its incentive fee and over 80 percent of its total fee.”⁵² This is significant for two reasons. First, if the CDR identifies significant issues with the FCS design or cost, there is little incentive fee available after CDR to encourage improved or more determined performance from the LSI. Second, the time between CDR and low-rate production is one of changing program emphasis that requires detailed and aggressive

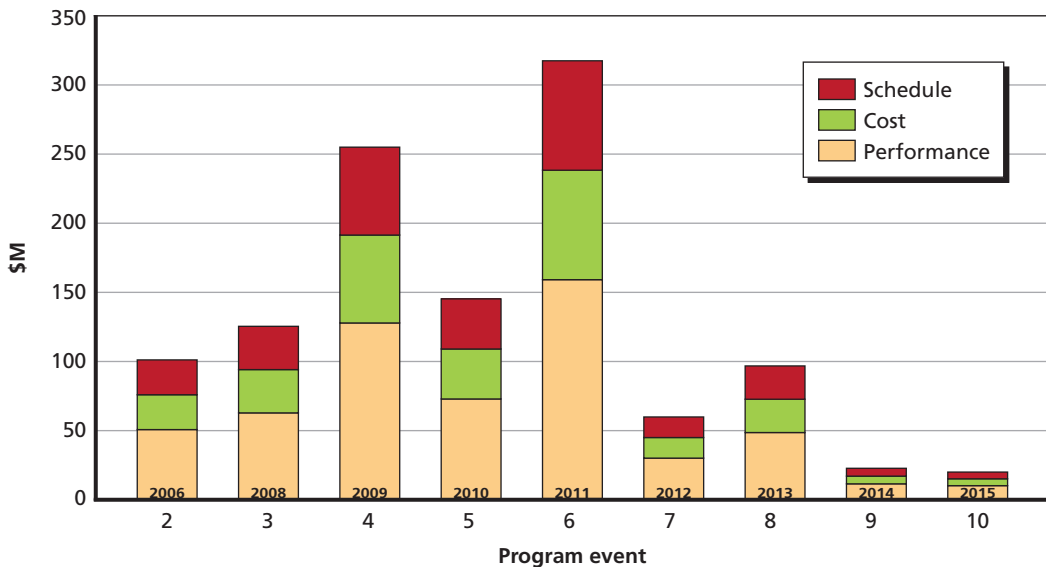
⁴⁹ DAAE07-03-9-F001, P00063, Article VIII.

⁵⁰ Award/Contract Between the Boeing Company and the U.S. Army Tank-Automotive Armament Command, Concerning Future Combat System (FCS) System Design and Development (SDD),” Contract No. W56HZV-050C-0724, September 30, 2005, Section H-106, September 30, 2005.

⁵¹ There was no event in 2007.

⁵² Government Accountability Office, *Defense Acquisitions: Role of Lead Systems Integrator on Future Combat Systems Program Poses Oversight Challenges*, 2007.

Figure 7.1
Incentive Fee Schedule



RAND MG1206-7.1

management to maintain schedule. Incentives can be a key tool for managing the push to production.

The decision to frontload the incentives was intentional. Interviewees noted that originally the incentives were intended to be more balanced across program events, but that the program’s government leadership decided it was important to incentivize strong performance early in the program in order to make the rapid progress demanded by the aggressive program schedule. Whether this was the correct strategy, or a conservative approach to incentives that preserved a greater amount for later in the program, may not be knowable following the program’s restructure in 2009.

Performance Incentives Were Problematic, as They Were Based on Completion of Program Events

Incentivizing performance on a developmental program, particularly one as complex as the FCS program, is difficult. First, the question of “what performance to emphasize through incentives” must be resolved. The obvious and easiest performance to measure would be objective criteria associated with the materiel being developed.⁵³ Unfortu-

⁵³ In fact, the FAR, while recognizing that performance incentives may be developed for services, states a preference for product-related performance incentives. As FAR Part 16.402-2 notes,

(c) Technical performance incentives may be particularly appropriate in major systems contracts, both in development (when performance objectives are known and the fabrication of prototypes for test and evaluation is required) and in production (if improved performance is attainable and highly desirable to the Government).

nately, this was probably not possible with the FCS program. To start with, FCS SoS performance was an emergent property. The shape of the FCS BCT and the doctrine it would employ were inevitably changing as FCS systems were developed together—in simulation and testing - and as soldiers, leaders, and doctrine developers worked with them. As happened during the program, system—as well as system-of-systems—characteristics changed significantly over the course of just a few years' development.⁵⁴ In a similar vein, but at a more technical level, SoS integration is a software and networking issue that undergoes constant development. It is inconceivable that such a software-intensive system as FCS (over 60 million lines of code) would not undergo constant and significant development during and after SDD. Defining FCS SoS attributes early in SDD, as would be required to establish incentives associated with them, was simply impractical.

Moreover, the FCS SoS attributes were also reliant on many factors beyond the control of the LSI. While the LSI was developing a great deal of the materiel that would have been part of the FCS BCT, other complementary programs that were not formally part of the FCS program were expected to provide much of the capability. For example, FCS network performance required a significant increase in bandwidth and this was to be provided by the JTRS, which was being developed in parallel with the FCS. As it turned out, the JTRS program would probably have been unable to deliver the required bandwidth, thus compromising the FCS network.⁵⁵

Finally, while the LSI had a lot of influence over FCS development, it did not control it and never had full SoS authority during SDD. Full SoS authority would have proceeded from performance specifications, such as the key performance parameters (KPPs), and used them to develop solutions that traded along the DOTMLP-F (doctrine, organization, training, materiel, logistics doctrine, personnel and facilities) dimensions to meet the specifications. That is not what occurred in the case of the FCS program. For the most part, the Army developed the FCS BCT organizational design and the doctrine and tactics that would have defined its behavior. And the operational requirements document (ORD) described the FCS not in broad SoS terms, which would have allowed the LSI more latitude to make the SoS trades, but rather at the individual system level. The government also exerted its authority on the engineering

(d) Technical performance incentives may involve a variety of specific characteristics that contribute to the overall performance of the end item. Accordingly, the incentives on individual technical characteristics must be balanced so that no one of them is exaggerated to the detriment of the overall performance of the end item.

⁵⁴ For example, and as noted elsewhere, systems were eliminated and added to the FCS BCT before and during SDD. Moreover, individual system specifications changed as designs matured. Most obviously, the weight of the manned ground vehicles increased at least 50 percent during SDD.

⁵⁵ In fact, the JTRS Ground Mobile Radio (GMR), a key piece of the FCS network, was ultimately cancelled. Kate Brannen and Michael Hoffman, "U.S. Army to Cancel GMR Contract, Seeks Replacement," *DefenseNews*, October 13, 2011.

development side of the program: the IPT structure and the rules governing it gave government engineers voice at all tiers of the complex program.

What is clear is that under the rules that governed the FCS program, the LSI could not have been held responsible enough for actual FCS BCT and individual system performance to be the basis for contractual incentives. Such performance-based incentives would have been difficult to deny, since the LSI could claim that it was not its contract execution that prevented FCS SoS performance, but rather Army decisions and direction. As a result, the “performance” incentives that were used for FCS SDD were based on the completion of program events, such as design reviews. This is problematic for two reasons. First, completion of these program events was the basis for the LSI contract in the first place. In other words, the Army contracted with Boeing to be the LSI for the FCS program and to manage the program in a competent manner, which means completing those tasks that define an SDD program. While a cost-type contract would require the payment of the fixed fee regardless of whether the program tasks were completed, lack of progress on the program tasks would also have resulted in contract termination. Providing an additional performance incentive to complete those tasks is, therefore, nearly the same as just increasing the fixed fee. Second, task completion criteria were necessarily subjective. The tasks were complete when the government personnel determined that documents were good enough and when something like a design review showed enough progress to move forward. Subjective assessments of programmatic progress are necessary and inevitable in a complex acquisition program, but they are not a good basis for awarding performance incentive fees.

Cost Incentives Were Primarily Designed to Meet AUPC Glide Path Targets

The cost incentives on the FCS SDD contract were not “cost incentives” in the traditional sense. Typically, cost incentives relate to the actual cost of performing a contract.⁵⁶ The FAR notes, for example, that cost incentives “take the form of a profit or fee adjustment formula and are intended to motivate the contractor to effectively manage costs.” There was no fee adjustment formula on the FCS SDD contract because the “cost” incentives were not about SDD costs. Instead, the cost incentives in the SDD contract were established to help control FCS life-cycle costs. SDD contract costs were

⁵⁶ FAR Part 16.402-1 Cost incentives:

- (a) Most incentive contracts include only cost incentives, which take the form of a profit or fee adjustment formula and are intended to motivate the contractor to effectively manage costs. No incentive contract may provide for other incentives without also providing a cost incentive (or constraint).
- (b) Except for award-fee contracts (see 16.404 and 16.401(e)), incentive contracts include a target cost, a target profit or fee, and a profit or fee adjustment formula that (within the constraints of a price ceiling or minimum and maximum fee) provides that—
 - (1) Actual cost that meets the target will result in the target profit or fee
 - (2) Actual cost that exceeds the target will result in downward adjustment of target profit or fee
 - (3) Actual cost that is below the target will result in upward adjustment of target profit or fee.

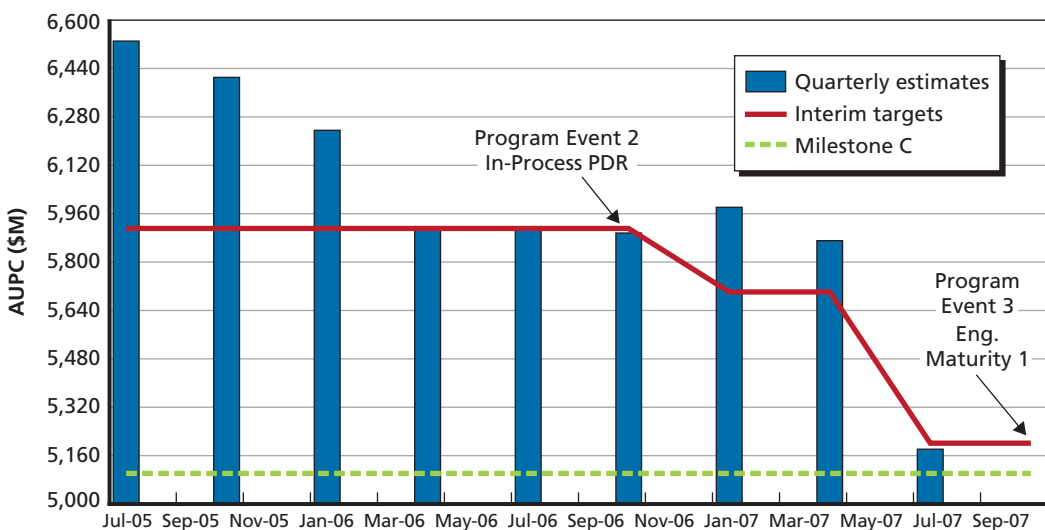
considered fixed in the sense that the program would use all funds allocated to it by Congress, and the level of effort would adjust in relation to the allocated amount.

As already described, the cost incentive came in two parts. The first required the development, implementation, and demonstration of a life cycle cost containment plan (LCCCP). The second part required continual improvement (reduction) of the estimated FCS AUPC along an agreed-upon AUPC “glide path.” The targets and estimates are shown in Figure 7.2.

In reality, then, these “cost incentives” were performance incentives since they were established to affect an aspect—life cycle cost—of the future FCS rather than the cost of the current contract. And, like the performance incentives above, they are subject to the comment that the incentive rewarded basic, rather than excellent, contract performance, particularly in the case of the incentive associated with the development of the LCCCP. Development of the LCCCP should be considered just another of the many tasks required in a materiel development contract and rewarded by a fixed fee. Moreover, assessment of the success of the LCCCP is subjective. The criteria established require delivery and acceptance of a quarterly life cycle cost estimate, the “consideration” of life cycle costs in design decisions and demonstration of an Affordability Initiative Process through specific examples. These are important criteria, but were not defined in a way that allowed objective assessment against a standard.

The incentive defined by the AUPC glide path attempts to establish an objective standard for assessing progress on life cycle cost. However, the LSI was incentivized only to meet the AUPC glide path targets and not the actual cost to produce an FCS

Figure 7.2
AUPC Glide Path and LSI Estimates of AUPC Cost



BCT. It is impossible now to know what the relationship between the glide path and the actual cost of an FCS BCT would have been, but there are certainly examples where the AUPC costs estimated during development were much lower than actual costs during production.⁵⁷ In the FCS case, the incentive to meet the AUPC glide path would have elicited optimistic estimates. This is because a complex cost estimate can be managed through optimistic assumptions and directions to improve the many cost components that seem too high. Without intending any deception and working in good faith, the paper estimates of AUPC should always meet the glide path laid out. The incentive rewards that outcome handsomely, and there is no penalty if the SDD AUPC cost estimates turn out to have been wrong.

Schedule Incentives Were Challenged by Inertia

The FCS schedule was considered critical for several reasons that can be traced back to General Shinseki's original intent to accelerate the program and have the first FCS BCT operational by 2011. This ambitious schedule was ultimately pushed back a few years, but schedule remained a critical metric for the program. The Army remained intent on getting the capability to soldiers and maintaining programmatic inertia and so used schedule incentives to manage LSI efforts.

The FCS SDD incentives were relatively simple. The LSI needed to meet the completion criteria for each incentive event within the threshold established in the Acquisition Program Baseline (APB)⁵⁸ and update the Integrated Master Plan (IMP) and Integrated Master Schedule (IMS) within a specified time period after each incentive event.

As with most of the performance and cost incentives, managing the FCS program to schedule is a basic LSI function and should not, therefore, have merited an additional incentive fee. FAR Part 16.402-3(a), which deals with schedule incentives, states that

Delivery incentives should be considered when improvement from a required delivery schedule is a significant Government objective. It is important to determine the Government's primary objectives in a given contract (e.g., earliest possible delivery or earliest quantity production).

In other words, schedule incentives should have been used to motivate the LSI to complete the incentive events more quickly than planned for in the APB. A more

⁵⁷ The littoral combat ship is a good example of a complex program that experienced very significant cost increases over estimates for the first unit produced. Renae Merle, "High Costs Lead Navy to Cancel Lockheed Coastal Vessel," *Washington Post*, April 13, 2007, p. D4. On the FCS program itself, the negotiations for the building of the NLOS-C prototypes resulted in significantly higher costs than were expected based on estimates provided during SDD.

⁵⁸ Or, if the APB did not establish a schedule threshold, within 90 days of the date established by the IMS.

effective method for managing schedule incentives would have been to apply them in a graduated manner to provide increased incentive for ever-improved schedule performance (and an increasing penalty for not meeting a threshold deadline).⁵⁹

In addition, it appears in retrospect that the schedule incentives lacked substance in another way. Over the course of the FCS SDD phase, several major program restructures occurred: reincorporating four systems in the 2004/2005 time frame, converting to a FAR-based contract in 2005, and the deletion of four systems and stretching out production plans in 2007.⁶⁰ Each of these FCS program restructures offered an opportunity to renegotiate and replan the details of the incentive event schedules. Several interviewees stated that one result of the frequent program restructures was that the government was unable to enforce previous program schedule details and could only agree with the LSI as to what could be done by when. In addition, the interviewees noted that the IMS was frequently updated to reflect program experience, thus adding a further inability to enforce strict schedule criteria. Because the schedule incentives did not encourage completing incentive events more quickly than the threshold schedule and because the schedule was frequently redefined at both the program and detail levels, the net effect was to make the FCS SDD schedule incentives perform more in the nature of additional fixed fee.

Conclusions and Lessons

Conclusions

The FCS program presented a challenging contracting environment for the Army. It was the most ambitious acquisition program ever attempted by the Army, was initiated about the same time the Army was committed to a war ill-suited to the strengths of the FCS concept, and was beset by political scrutiny that had its origins in another service. As a result of these various factors, the FCS program suffered significant instability that affected the contracting environment. The Army attempted to manage the relationship with the LSI through innovative contracting strategies, including the use of the “other transaction” and attempts to structure and incentivize a “partnership” between the LSI and the Army. As should be expected when innovating, a number of important contracting lessons emerged from the FCS program.

⁵⁹ All-or-nothing schedule incentives, as appear to have been used during FCS SDD, may also result in unintended LSI behaviors. Because so much is on the line as the deadline approaches, the LSI may cut corners, intentionally or accidentally, to save the payout. Perhaps worse, should the schedule deadline get missed, there is no more reason to push hard to recover schedule.

⁶⁰ In addition, the decision to accelerate spin-outs occurred in SDD, though it is unclear how this affected schedule on the main program.

Lessons

Government control over significant elements of the system of systems may make incentive fees inappropriate. The FCS program structure made it difficult to award the LSI less than all available performance fees. The government retained such significant control over so many of the factors that would affect FCS SoS behavior (doctrine, organization, training, system-level requirements) and because it was embedded into the IPT structure with some level of authority, the LSI could always point to government actions as a proximate cause of performance issues.

Performance incentives that are not tied to actual product performance may not result in effective outcomes. The ambitious performance goals and aggressive schedule for the FCS program destined it to unstable requirements. Performance incentive fees based on actual product performance cannot be realistically drafted when product requirements cannot be fixed.

Programs with a combination of unstable requirements and complex integration have very significant performance, cost, and schedule uncertainty, thus making objective assessments for rewarding incentives nearly impossible. As the FCS case demonstrates, significant performance, cost, and schedule uncertainty needs to be mediated through contract design. This means that award and fixed fee contracts are preferable in these cases over incentive contracts.

Schedule and cost incentives should only be used if they can be structured to motivate improved contractor performance. The FAR advises that schedule and cost incentives should reward improved, rather than expected, performance.

Early commitment of incentive fee reduces the available fee late in the program. Early commitment can also significantly reduce the government's ability to motivate contractor behavior as the program enters final design and test and moves to production.

Technology Choices and Development in FCS

Previous chapters have considered FCS from a requirements, program management, and contract perspective. FCS technologies provided the materiel solution for Army modernization embodied by the Objective Force,¹ requiring simultaneous development of several novel technologies. This chapter explores several aspects of the technologies themselves as well as the planning and execution of the technology development process. It follows the critical technologies over time, and describes a few of the more revolutionary expectations included in the FCS program.

The breadth of different critical technologies necessitated solutions from a community of developers external to the program, including several S&T organizations and complementary programs. The complexity of designing a system of networked systems to implement new concepts of operation had broad implications for Army capabilities, yet required many facets of technology development that are commonly employed, such as risk management, testing, modeling and simulation (M&S), and analysis. Although there is no coherent catalog of technology outputs resulting from FCS, our interviews with program officials and survey of official program documents have revealed several examples of technologies that benefited from development under FCS.

Past Technology Development Processes Were Foundational to FCS

FCS was defined early on as “the central materiel solution to achieving the Objective Force capabilities.”² Yet to characterize FCS as just another materiel solution would be inaccurate; rather, it was considered the “number one priority for Army investments” and “the foundation of the future transformed Army.”³

¹ “2001 Army Modernization Plan,” 2001.

² “2001 Army Modernization Plan,” 2001.

³ “2001 Army Modernization Plan,” 2001.

In total, 54 critical technology elements (CTE) or subelements were identified, upon which the system-of-systems performance was thought to rest.⁴ Developing this diverse set of novel technologies would necessitate a broad reliance on the S&T community, several complementary programs, and internally developed technologies within the FCS program. The reliance on S&T to enable timely fielding of the Objective Force and FCS was not only a modernization tenet⁵ but rather a mandate making development of FCS “the Army S&T community’s unconditional highest priority.”⁶

Despite its many differences from previous acquisition programs, FCS shared processes found in any technology development effort. These common aspects include risk management, testing, analysis, and M&S. Although these processes are commonly found in major programs, their planning and execution differed from standard practice to account for the novelty of technologies, the breadth of supporting programs, and the complexity of SoS engineering.

Deployability and Connectivity Were Fundamental Tenets of FCS

As a consequence of the Army’s challenges in deploying heavier ground vehicles in the Balkan wars, General Shinseki articulated a vision of an Objective Force composed of lighter manned ground vehicles. The Objective Force envisioned deployment of a combat capable brigade anywhere in the world in 96 hours⁷ enabled by lighter vehicles weighing approximately 20 tons. The survivability of these manned ground vehicles, in contrast to past systems, would rely on advanced armor technologies, passive and active protection systems, unprecedented situational awareness, and “mutual interaction between platforms and dismounted soldier.”⁸ Integrating and designing interactions among systems (including the soldier, viewed as a system) to produce unique effects is a defining characteristic of a SoS,⁹ and FCS from its initial solicitation was required to be a “system of systems based on advanced technologies that facilitate enhanced capabilities in lethality, survivability, situational awareness, mobility, deployability, supportability, and sustainment.”¹⁰ A proposal from the future LSI emphasized the criti-

⁴ “Critical” technologies are those essential to performance and are either substantially new or a novel application of known technologies.

⁵ “2001 Army Modernization Plan,” 2001.

⁶ “2001 Army Modernization Plan,” 2001.

⁷ “2001 Army Modernization Plan,” 2001.

⁸ “2001 Army Modernization Plan,” 2001.

⁹ Department of Defense, Defense Acquisition University, *Defense Acquisition Guidebook*, Chapter 4, “System of Systems Engineering,” October 14, 2004. Note that in this research we consulted editions of this guidebook from several different years of issue.

¹⁰ “Future Combat Systems Solicitation (FINAL),” Federation of American Scientists, no date.

cal role of a SoS concept to enable survivability through greater situational awareness: “Our approach to survivability is based on the attributes of an integrated SoS; and on information dominance that is inherent in our force concept and empowers unparalleled increases in survivability.”¹¹ Ensuring survivability of vehicles that shed traditional heavy armor requires unprecedented situational awareness, which contractors were fully aware of: “At the SoS level, our C4ISR capability is the most prominent contributor to our survivability.”¹² The pervasive connectivity required between manned and unmanned sensor systems to enable greater situational awareness would rely on a Mobile Ad-Hoc Network (MANET), a type of network requiring new conceptual breakthroughs and technological advances.

Even before the network developmental challenges encountered by the program, there was skepticism about FCS concepts, including the notion that remote assets can ensure adequate situational understanding.¹³ As the program progressed, the goal of achieving a tradeoff between armor and the situational awareness was hampered by several technology development challenges: pursuit of multiple novel technologies with ambitious goals, reliance on multiple complementary programs and S&T, and enhancement of standard practices, such as risk management, M&S and analysis, and testing to contend with the complexities of SoS acquisition. Before examining each of these challenges, we summarize the various systems and changes in the SoS composition throughout the program.

FCS as a System of Systems: The 18+1+1 Concept

The FCS SoS consisted of 18 systems: eight types of Manned Ground Vehicles (MGV), three Unmanned Ground Vehicles (UGV), four classes of Unmanned Aerial Vehicles (UAV), two Unmanned Ground Sensors (UGS), Non Line of Sight Launch System (NLOS-LS), and the Intelligent Munitions System (IMS). In addition, all soldiers in the Unit of Action (UA) are part of the Soldier as a System (SaaS), an overarching requirement encompassing everything the soldier wears, carries, and consumes, including unit radios, crew served weapons, and unit-specific equipment in the execution of tasks and duties.¹⁴ These 18 platforms and the Soldier would be connected by an advanced set of technologies forming the MANET and enabling C4ISR and situational awareness capabilities on the move at “levels of joint connectivity, situational

¹¹ Boeing Company, “Proposal to DARPA/Army for the Future Combat Systems, Volume 1: SoRC Compliance over Time,” unpublished proposal, January 17, 2002, p. 110.

¹² Boeing Company, “Proposal to DARPA/Army for the Future Combat Systems, Volume 1: SoRC Compliance over Time,” unpublished proposal, January 17, 2002, p. 110.

¹³ John Matsumura et al., *Exploring Advanced Technologies for the Future Combat Systems Program*, Santa Monica, Calif.: RAND Corporation, MR-1332-A, 2002.

¹⁴ Program Manager Future Combat Systems Unit of Action, *Army 18+1+1 White Paper*, Point of Contact COL Robert Beckinger, TRADOC System Manager, October 15, 2004.

awareness and understanding, and synchronized operations heretofore unachievable.”¹⁵ This collection of 18 systems, the Network, and the Soldier are referred to as “18+1+1” systems comprising the FCS SoS.

Broad expectations for the FCS SoS were articulated in the initial solicitation issued by DARPA and the Army.¹⁶ The concepts proposed by four contractor teams for the FCS SoS were developed during the Concept and Technology Demonstration (CTD) phase. In addition to foreshadowing concepts that would later appear in the acquisition and technology development strategy for the SDD phase, such as Simulation Based Acquisition (SBA) and Simulation and Modeling for Acquisition, Requirements and Training (SMART), the solicitation also emphasized a SoS concept that “may require advanced technologies,” and encouraged proposals of “capabilities that do not yet exist.” Complementing this high-risk SoS acquisition strategy, the solicitation ensures risk reduction through parallel technology development efforts through future DARPA research announcements (RA) or broad agency announcements (BAAs), while encouraging system concept developers to consider how these parallel DARPA and Army efforts could be integrated into the FCS program. The various Technology Transition Agreements (TTAs) that were signed between the S&T base and the program can be seen as one manifestation of this risk-reduction strategy.

Specific key technological areas of interest highlighted include:

1. Network command and control of direct and indirect fire robotic systems
2. High-speed, autonomous robotic navigation
3. Anti-jamming (guaranteed communication) networks
4. Network security for command and control of distributed robotic systems
5. Control of robotic sensors.

In hindsight, some of the platforms and CTE eventually selected can be understood as arising from the vision set forth in this initial solicitation. For example, the NLOS-LS platform clearly requires networked C2 of unmanned indirect fires. Similarly, the various UGV (SUGV, MULE Transport, MULE Countermine, ARV-Assault-Light, and ARV) required high-speed robotic navigation. The other technological areas are natural consequences of relying on networked robotics, which require information assurance such as network security and reliability for control of not only the platforms, but also sensors placed on the platforms to guarantee a level of situational awareness required by the operational concept.

Requirements that would continue to challenge developers through SDD, such as a maximum system (platform) weight and C-130 transportability in a combat-ready configuration, also appear in this solicitation. The solicitation states explicitly that

¹⁵ Program Manager Future Combat Systems Unit of Action, *Army 18+1+1 White Paper*, 2004.

¹⁶ “Future Combat Systems Solicitation (FINAL),” 2011.

the “FCS solution will not be a single vehicle system.” Although there are no explicit guiding principles for any proposed force structure, the solicitation does list requisite missions the SoS must be able to execute, including: direct/indirect fires, air defense, reconnaissance, troop transport, C2, non-lethal, mobility/countermobility, and combat support. Just as some of the key technological areas can be seen as substantiating the inclusion of robotic platforms, one can generally understand the 18 systems as serving specific functions within a mission. Force-on-force simulations and other analysis would eventually be used to select the best force structure concept, yet it is nontrivial to prove that any particular combination of platforms is optimal, primarily due to the multitude of tactical, operational, and network performance assumptions required for any force-on-force simulation. Nonetheless, the categories of platforms, MGV, UGV, UAS, UGS, and unattended munitions are reasonable representations of the requisite capabilities stated at the outset of the concept design phase.

Although envisioned as 18 systems, FCS initially received funding for only 13.¹⁷ Five systems in 2003 would be “spiraled forward” during Increment 1 development, being deferred until the program’s funding profile would allow their integration. The five systems included the Intelligent Munition System (IMS), the Class II and III UAVs, Armed Robotic Vehicle (ARV) Assault and Reconnaissance variants, and the FCS Recovery and Maintenance Vehicle (FMRV), one of eight MGVs. However, following Milestone B, a July 2004 restructuring of the program restored these five deferred systems.¹⁸ A second program restructuring in January 2007 led to the cancellation or separation of four of the five initially deferred systems.¹⁹ The Class II and III UAVs were required to be removed from the SDD contract with a stop work order, and would not be developed further during the program. The ARV-A and ARV-R were also removed from the SDD contract and transitioned to Army S&T for further development, removing most of the robotic assault and reconnaissance capability from FCS.²⁰ The fourth system to be removed from the SDD contract in 2007 was the IMS, which subsequently continued development under the PM-CCS Scorpion program.

In a complex SoS, consisting of a specific composition of systems, any deletion can cause unintended changes in requirements on the remaining platforms due to the highly linked nature of SoSS design. Although TRAC led an analysis of alternatives (AoA) update to address FCS effectiveness in light of the reduced force structure at

¹⁷ Lieutenant General Benjamin S. Griffin, Deputy Chief of Staff, G-8, “Review of FCS Affordability and the Army Cost Position (ACP),” U.S. Army memorandum, April 17, 2003.

¹⁸ “FCS Acquisition Program Baseline (APB),” November 4, 2005, Section C. Not available to the general public. The restructuring of July 21, 2004 extended the original program by four years and increased the scope from the March 2003 Army Cost Position.

¹⁹ Claude Bolton, “Memorandum for Program Manager, Future Combat Systems (Brigade Combat Team),” January 11, 2007.

²⁰ Will Brooks, Phil Beavers, and Robert Miele, *FCS Platform Capabilities for AoA (Block 1 Unconstrained vs. Increment 1)*, March 28, 2003. Not available to the general public.

the Milestone B decision,²¹ there are examples of unintended system design consequences. An example is the removal of the Class II UAV, which served as the designator for medium-range munitions, a function that had to then be imposed on the Class I UAV, subsequently increasing its fuel requirement and thus backpack weight for soldier transportability.²² Also affected by the Class II cancellation was the countermine MULE, which was limited to travel at six kilometers per hour in scan mode, relying on the Class II to fly ahead with its sensor array and relay back to the MULE.

Table 8.1 summarizes the 2009 status of all 18 systems and the primary contractors responsible for development activities. Further details about each system and its history throughout the program can be found in Appendix E.

FCS Relied Heavily upon Novel Technologies

Delivering FCS required overcoming many innovation challenges, including coordination with and integration of various complementary systems outside its management, complex SoS design, and simultaneous development of multiple novel technologies. In this section we focus on the process used and progress made in FCS for developing and assessing multiple novel technologies, examining in detail four of the more ambitious examples.

Some FCS Technologies Did Not Meet TRL Guidelines at Milestone B

Technology readiness levels of critical technologies are but one means of tracking technology development through acquisition programs. In a program the size of FCS, considerable effort across government and contractor staff is put on assessing technology development in direct support of meeting overall system requirements. In the FCS program, multiple parallel processes were at work.

For instance, a technology gaps analysis produced assessments of how close the program was in meeting its ORD requirements. A snapshot assessment in 2006²³ found that of the 551 objective ORD requirements at the time, about 20 percent were assessed as being beyond currently available technology. This translated into several SoS-level objective requirements being unobtainable as well. A similar view of meeting threshold requirements was less dire, but still a cause for concern.

Along with technology gaps analysis, the program and the government engaged in hundreds of engineering trade studies to help better define risks and options for

²¹ "Future Combat Systems (FCS) Analysis of Alternatives (AoA) Update—Executive Summary," TRADOC Analysis Center, October 15, 2004. Not available to the general public.

²² Interview data.

²³ "FCS Technology Gaps Analysis," Rev. A, Technology IPT, CDRL A-0002, Document D786-12047-1, September 2006.

Table 8.1
Summary of 18 Platforms

	Platform Name	Developer	Outcome
MGV	Mounted Combat System (XM1202)	General Dynamics	PDR; cancelled '09
	Infantry Carrier Vehicle (XM1206)	BAE	PDR; cancelled '09
	Non Line of Sight Cannon (XM1203)	BAE	5 prototypes; cancelled '09
	Non Line of Sight Mortar (XM1204)	BAE	PDR; cancelled '09
	Reconnaissance and Surveillance Vehicle (XM1201)	General Dynamics	PDR; cancelled '09
	Command and Control Vehicle (C2V)	General Dynamics	PDR; cancelled '09
	Medical Vehicle-Evacuation (XM1207)	BAE	PDR; cancelled '09
	Field Recovery and Maintenance Vehicle	BAE	PDR; cancelled '09
UAV	I	Honeywell (called T-Hawk MAV)	E-IBCT: cancelled in LRIP
	II	Piasecki Aircraft Corp	Cancelled in '07; Began as 10-month contract in '05
	III	Contestants: Teledyne, AAI Corp., Piasecki	Cancelled in '07; Began as 10-month contract in '05
	IV	Northrop Grumman (called Firescout; new version Fire-X)	
UGV	Armed Robotic Vehicle (Assault and RSTA)	BAE and General Dynamics Robotics Systems	TARDEC ATO (RVCA), APD, ART/ATO
	Small Unmanned Ground Vehicle (XM1216)	iRobot (new version: 710 Warrior)	E-IBCT: continues in LRIP
	Multifunctional Utility/Logistics and Equipment Vehicle	Lockheed (has MULE-like transport vehicle called SM55)	
UGS	Tactical and Urban	Textron Systems	E-IBCT: cancelled during LRIP
	NLOS-LS	Raytheon and Lockheed (known as NetFires LLC)	Cancelled in E-IBCT, Littoral Combat Ship
	IMS	Textron Systems	Separated in '07; PM-CCS, named Scorpion, Spider

meeting requirements. These studies ranged far and wide within the program. A complete meta analysis is not appropriate for this study; however, considerable knowledge has been built through these studies, and in them exists a body of potentially usable material for future acquisition programs which should be sought.

A more tractable option is to follow the critical technology elements as they developed during the program to help understand the challenges and lessons involved. CTEs are new or novel technologies either themselves or in their application within an acquisition program. In addition, CTEs are considered necessary for the system to meet operational requirements, or present a major technological risk.²⁴ The list of identified CTEs²⁵ is expected to change over a program's lifetime,²⁶ as it did in the case of FCS.

The maturation of CTEs is evaluated at multiple points in a program by using technology readiness levels (TRLs), a numerical²⁷ scoring system developed originally by NASA²⁸ to summarize the state of maturity for a given technology. In addition to other possible evaluations, an Independent Review Team (IRT) is responsible for conducting technology readiness assessments (TRAs), which are reviewed and evaluated by officials in both the service and OSD.²⁹ The TRA is a formal process to evaluate the maturity of CTEs and is required³⁰ for all DoD acquisition programs prior to Milestone B and C approval.

Currently, all CTEs are required by law³¹ to be demonstrated in a relevant environment, equivalent to TRL 6, before Milestone B approval, unless such a requirement would hinder DoD's ability to meet critical national security objectives, in which case a waiver may be granted. Approval for Milestone C, which allows a program to enter low-rate initiation production (LRIP), expects each CTE to be TRL 7 or higher.³²

²⁴ Department of Defense, *Technology Readiness Assessment (TRA) Deskbook*, prepared by the Director, Research Directorate (DRD) of DDR&E, July 2009.

²⁵ Critical technology elements should not be confused with critical technology events, key decision points in weapon systems development, which are also rated with technology readiness levels in some publications, e.g., "Critical Technology Events in the Development of Selected Army Weapons Systems: A Summary of 'Project Hindsight Revisited,'" NDU CTNSP, September 2006.

²⁶ *TRA Deskbook*, 2009.

²⁷ Numerical values for TRL range from 1 to 9 for least to most mature. The state of technological maturity corresponding to each TRL level for hardware and software can be found in the *TRA Deskbook*.

²⁸ John C. Mankins, "Technology Readiness Levels: A White Paper," Advanced Concepts Office, Office of Space Access and Technology, NASA, April 6, 1995.

²⁹ *TRA Deskbook*, 2009.

³⁰ *TRA Deskbook*, 2009.

³¹ United States Code, Title 10, Section 2366b, U.S.C. January 7, 2011. Also see footnotes in the *TRA Deskbook* on relevant USD(AT&L) memoranda amending this statute.

³² *TRA Deskbook*, 2009.

In 2003 PM FCS identified 31 CTEs from more than 700 technologies surveyed by the LSI and the FCS Science and Technology IPT.³³ The CTEs were organized into groups corresponding to KPPs used in FCS requirements: Joint Interoperability, Networked Battle Command, Networked Lethality, Sustainability/Reliability, Training, Deployability, and Survivability. A technology maturity assessment (TMA) was conducted by PM FCS,³⁴ providing a TRL rating for each CTE, which was subsequently reviewed against requirements and KPPs specified in the ORD by an Independent Review Team (IRT) organized by the Deputy Assistant Secretary of the Army for Research and Technology (DASA(R&T)). Evaluation of CTEs by the IRT was used to produce a Technology Readiness Assessment (TRA), which was presented by DASA(R&T) in April 2003 for the Milestone B review of FCS.³⁵ The TRA described the process for the identification of CTE and TRL for each one.

The 2003 TRA evaluated all 31 CTEs, but only seven³⁶ were at the desired maturity of TRL 6. The Director of Defense Research and Engineering (DDR&E) concurred “with caution” in a May 2003 memo, but further required PM FCS to develop detailed risk mitigation plans for the remaining 24 CTEs to be delivered at the November 2004 Milestone B update.³⁷

The FCS program further refined the CTEs over the course of the program as technology solutions were more specifically identified and assessed. The 2004 TRA produced for the Milestone B update reevaluated the CTEs resulting in a subdivision of the 31 CTEs into 55 CTEs for purposes of better risk management and technology maturation.³⁸ This list of 55 CTEs was reduced to 44 CTE for various reasons, including lack of government standards necessary for the technology; additional information about the technology rendered it too expensive in terms of personnel, space, weight, and power (SWaP), or cost; operational environment limitations; the lack of relevance to

³³ “FCS INC I Tech Readiness Assessment,” signed by A. Michael Andrews, April 14, 2003. Not available to the general public.

³⁴ “FCS Technology Maturity Assessment,” BG Schenk, PM FCS (no signature on document), March 5, 2003. Not available to the general public.

³⁵ “FCS Technology Maturity Assessment,” 2003.

³⁶ See “FCS INC I Tech Readiness Assessment,” 2003, and “FCS TRA Review, DUSD(S&T),” May 2003. Not available to the general public.

³⁷ Charles J. Holland, Deputy USD (S&T), “FCS TRA,” memorandum, May 6, 2003.

³⁸ See “Future Combat Systems (FCS) Increment I Technology Readiness Assessment (TRA) Update,” Office of the Deputy Assistant Secretary of the Army for Research and Technology, submitted by Mr. Robert Saunders, Acting Director for Technology, Office of Deputy Assistant Secretary (Research and Technology), approved by Thomas H. Killion, Deputy Assistant Secretary of the Army for Research and Technology, October 2004 (no signature on file). Not available to the general public. Note that prior to this subdivision of CTEs, an additional CTE, for Class I UAV propulsion, was added, bringing the total to 32. The final number of CTEs, 55, although reported as such in the 2004 TRA, in later TRAs is confusingly reduced to 54 as CTE2A (interface and information exchange, army) and CTE2B (interface and information exchange, joint and multinational) are counted as one CTE (see, for example, May 2009 TRA).

any KPP; no longer complying with the definition of a critical technology.³⁹ A total of ten CTEs were eventually removed in a series of working-level integrated product team (WIPT) meetings, which occurred in November 2005, January 2006, and May 2007.

Identification of CTEs is required by DoD acquisition policy but is also considered good system engineering practice to avoid performance, cost, or schedule penalties, which can result from overlooking or underestimating the criticality of a technology.⁴⁰ Conversely, identifying too many technologies as critical could lead to an improper allocation of limited resources available for technology development.⁴¹ However, the addition and deletion of CTEs is to be expected when a program embarks on fundamentally new CONOPS that rely on multiple novel technologies, as the evolution of understanding the relevance of each CTE to SoS functionality can only develop over time as technologies are matured and true capabilities and limitations are apparent. FCS articulated⁴² this incremental understanding of technologies from its inception.

IRT Membership and Capabilities Were a Challenge

Besides identification of CTEs, an equally important task is the accurate assessment of the wide range of technologies in a timely manner to affect changes in technology development when needed. The ASA(ALT) relies on an IRT to assess each CTE with a Technology Readiness Level (TRL).⁴³ The IRT panel would consist of senior-level personnel with technology development experience drawn from DoD organizations, including DARPA, Army Science Board, FFRDCs (e.g., MITRE), and industry.⁴⁴ A wide range of scientific and engineering disciplines were required to assess the maturity of all 44 CTEs.

An Independent Review Team is a temporary body composed of experts who are free of conflicts of interest with an acquisition program that they are tasked to evaluate. These teams are used to report on program challenges and risks.

The Defense Science Board (DSB) has reported that all too often IRTs do not actually have the independence or the expertise required to provide useful advice to

³⁹ Allan M. Resnick, Director, Requirements and Integration, "Memorandum for Program Manager Unit of Action," February 14, 2005.

⁴⁰ Tommer R. Ender, Tom McDermott, and Dimitri Mavris, "Development and Application of Systems Engineering Methods for Identification of Critical Technology Elements During System Acquisition," 7th Annual Conference on Systems Engineering Research, 2009.

⁴¹ Ender, McDermott, and Mavris, 2009.

⁴² "Future Combat Systems System Development and Demonstration Phase Technology Development Strategy," D786-10068-1, Release/Revision C, Spiral Development and Technology Planning IPT, Andrew Wold (signature on ACE dated September 19, 2002), February 28, 2004. Not available to the general public.

⁴³ John J. Young, Under Secretary of Defense for Acquisition, Technology and Logistics, "Operation of the Defense Acquisition System," DoD Instruction 5000.2, December 8, 2008.

⁴⁴ See, for example, Dr. Frank Fernandez, Chairman, "Independent Review of Technology Maturity Assessment for Future Combat Systems," 2005 IRT Outbrief, Milestone B Update Follow-On Assessment, April 5, 2005. Not available to the general public.

defense programs.⁴⁵ Indeed, the DSB has recommended the use of truly independent review teams (TIRT) that fully satisfy the intent of an IRT. The board identifies professional diversity as a prime requirement. It recommends that one way to provide diversity is to assure adequate representation from government, academia, and industry. A 2010 RAND study⁴⁶ for the VCSA reached similar conclusions. It recommended that the components of a red team have a core membership drawn from science boards, FFRDCs, war colleges, academia, and industry. The report also advocated the use of non-Army staff, both on the core team and for its IRT staff.

While IRTs were employed to provide some oversight of the FCS program, they were not seen as entirely effective. Our interviews have indicated that at times the program lacked clarity of what was expected from the IRT for each CTE to be judged at a particular TRL rating.

An IRT augmented with practitioners, dedicated to the IRT process and timeline rather than as informal SMEs, can better understand technical criteria from the PM for each CTE to ensure a common understanding of specific benchmarks for TRL ratings, prior to the assessment cycle.

Some Technologies Reduced in Maturity over Time

Altogether, FCS had four TRA that were produced by DASA(R&T):

1. February 2003; DASA(R&T) convenes IRT to assess critical technologies for Milestone B in May 2003, approved TRA dated April 14, 2003 (Dr. Andrews, DASA(R&T))
2. October 2004; Increment 1 TRA update as required by May 2003 ADM to update status of critical technologies at November 2004 update. It is notable that the TRA highlights “The major finding of the IRT was that, “There are no “show-stoppers” in the assessment of critical technology Technology Readiness Levels (TRLs)’ at this time.”
3. April 2006: TRA to support Spin-out 1 for the DAB Interim Program Review in May 2006. Spin-out 1 has only seven critical technologies.
4. May 2009: To support PDR in 4th quarter of FY09. Consolidation of four IRT reviews that took place prior to May 2009.⁴⁷ During this time only 44 CTEs

⁴⁵ Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Defense Science Board 2006 Summer Study on 21st Century Strategic Technology Vectors*, Vol. IV, February 2007.

⁴⁶ Joel B. Predd and John E. Peters, *Army Red Teaming*, Santa Monica, Calif.: RAND Corporation, 2011. Not available to the general public.

⁴⁷ See FCS TRA 1, May 2009: 16 critical technologies reviewed in January 27, 2009 TRA; seven critical technologies reviewed in April 8–10, 2008 TRA; five critical technologies reviewed in January 27–30, 2009; seven critical technologies reviewed in February 17–26, 2009; nine critical technologies to be reviewed in July 20–23, 2009 after 30-node network assessment.

remained from the original 54, as the remaining were judged to be no longer relevant.

Each of the four TRAs relied on an IRT to evaluate the CTE based on data provided by the LSI and PM. An additional IRT assessment of CTE was performed in March 2005 as a Milestone B update follow-on assessment.⁴⁸ There are three IRT assessments that show the evolution of FCS CTE maturity throughout the program's history:⁴⁹ September 2004 Milestone B update, March 2005 Milestone B update follow-on, and January/February/May 2009. The TRL scores provided by the IRT (shown in Table 8.2) reflect the IRT's view on technology maturity as reported in the TRA and differ at times from the PM/LSI's technology maturity assessment ratings. The GAO reported TRL scores for the 44 remaining CTEs from 2006, 2007, and 2008 using "Army data," which differ from the IRT scores shown in the table.

In 2008, several CTEs had decreased in TRL from the start of the program, for a variety of reasons.⁵⁰ Our look at the TRL ratings from the IRTs generally confirms other assessments, albeit with some discrepancies. Some decreases in TRLs were associated with changes to the WIN-T program, rather than FCS, and were the result of OSD assessments of WIN-T that were matched by the FCS program.⁵¹ In the case of others, like Rapid Battlespace Deconfliction, the TRL decreased as the definition for the technology was expanded to include indirect fires deconfliction in addition to airspace deconfliction.⁵² Other reasons for lowered readiness ratings include changing the source of technology to a less well-developed technology than originally planned.⁵³

All in all, our look through the IRT ratings contains four cases,⁵⁴ which *decrease* in TRL rating as the program progressed. All of the decreases occur in the earlier assessments between 2004 and 2005. Both decreases and the extended period from

⁴⁸ Dr. Frank Fernandez, Chairman, "Independent Review of Technology Maturity Assessment for Future Combat Systems," 2005 IRT Outbrief, 2005.

⁴⁹ We do not use the 2003 IRT assessment, as the identification of CTEs was not yet refined to the 55 CTEs evaluated from the 2004 Milestone B update and onward. Also, we do not use the 2006 IRT ratings, as they are for a limited set of CTEs and evaluated with different criteria appropriate for Spin-out 1.

⁵⁰ Lieutenant Colonel Michael Murrah, "Future Combat Systems Critical Technologies and Special Topics," Future Force Integration Directorate DASC, March 28, 2008, and FCS response to GAO 408, 409, 467.

⁵¹ Murrah, "Future Combat Systems Critical Technologies and Special Topics," 2008.

⁵² Note that the GAO report TRL numbers do not match those of the IRTs compiled for this project, and thus Rapid Battlespace Deconfliction is not shown as decreasing over time.

⁵³ Government Accountability Office, *Defense Acquisitions: 2009 Is a Critical Juncture for the Army's Future Combat System*, Washington, D.C.: Government Accountability Office, GAO 08-408, March 2008.

⁵⁴ In the case of CTE25A, Active Protection Systems, this decrease occurs because of the selection of a new and less mature technology compared with original plans. In the other cases showing decreases in TRL, namely, High Density Packaged Power (CTE31), High Power Density Engine (CTE20A), and Intrusion Detection—IP network (CTE3B1), the 2005 IRT briefing does not explain any particular reason for this decrease.

Table 8.2
Critical Technology Element Technology Readiness Levels over Time

	CTE #	Sub-Cat	2004	2005	2009
1	1A	JTRS – GMR	5	5	5
2	1B	JTRS – HMS	5	5	5
3	1C	WIN-T Software Radio	5	5	6
4	2A	Interface & Info Exchange – Army	4	4	6
5	2B	Interface & Info Exchange – Joint and Multi-National	4	4	6
6	2C	WIN-T Strategic Communications/SoSCOE Interoperability	4	4	6
7	3A	Cross Domain Guarding Solutions	3	4	6
8	3B1	Security Systems & Algos – Intrusion Detection IP Network	5	4	6
9	3B2	Security Systems & Algos – Waveform Protocols	3	3	5
10	4	MANET Protocols	5	5	5*
11	5	QoS	5	5	6
12	6	Unmanned Systems Relay	5	5	X
13	7A	Wideband Networking Waveform	5	5	5*
14	7B	Soldier Radio Waveform	4	4	6
15	8	Advanced Man Machine Interfaces	5	6	6
16	9	Multi-Spectral Sensors and Seekers	6	6	6
17	10	Decision Aids/Intelligent Agents	6	6	6
18	11A	Air-to-Ground (Rotary Wing/UAV)	6	6	6
19	11B	Air-to-Ground (Fixed Wing)	4	NR	X
20	11C	Ground-to-Air	3	NR	X
21	11D	Ground-to-Ground (Mounted)	6	6	6
22	11E	Ground-to-Soldier	4	NR	X
23	12	Rapid Battlespace Deconfliction	4	5	5
24	13A1	Sensor Data Fusion – Distributed Fusion Mgmt	4	4	6
25	13A2	Sensor Data Fusion – Level 1 Fusion Engine	6	6	6
26	13B	Sensor/Data Fusion and Data Compression Algos	6	6	6
27	14	Dynamic Sensor-Shooter Pairing Algos and Fire Control	5.5	5.5	6
28	15A	Precision Munition Guidance – PGMM	5	5	X
29	15B	Mid Range Munition Precision Munition Terminal Guidance	4.5	5	6
30	15C	Excalibur Precision Munitions Term Guidance	5.5	6	6
31	15D	NLOS-LS Terminal Guidance	5	5	6
32	16A	Aided Target Recognition for RSTA (AiTR) – Ground Only	5	5	5
33	16B	NLOS-LS Automatic Target Recognition Seekers	5	5.5	6
34	17	Recoil Management and Lightweight Cannon	5	6	6
35	18	Distributive Collaboration of UGVs	5	5	6
36	19B	Rapid BDA – Decision Aids & Algos	4	X	X
37	20A	High Power Density Engine	5	4.5	6
38	20B	Fuel-Efficient Hybrid Electric Propulsion	6	6	6
39	21	Embedded Predictive Log Sensors and Algos	4.5	5	X
40	22A	Water Generation From Exhaust	5	X	X
41	23	Computer Generated Forces	6	6	6
42	24	Embedded Tactical Engagement Simulation System	4	4	6
43	25A	Active Protection System	6	4.5	6

Table 8.2—continued

	CTE #	Sub-Cat	2004	2005	2009
44	25B	APS Threat Warning Sensor	4.5	4.5	6
45	26A	Signature Management	5	5	6
46	27	Lightweight Hull and Vehicle Armor	5	5	6
47	28	Health Monitoring and Casualty Care Interventions	6	6	6
48	29	Power Distribution and Control	5	X	X
49	30A	Advanced Countermine Tech – Mine Detection	6	6	6
50	30B	Advanced Countermine Tech – Mine Neutralization	6	6	6
51	30C	Advanced Countermine Tech – Efficient Resource Use	6	6	X
52	30D1	Hull Anti-Tank Mine Blast Protection	4	4	6
53	31	High Density Packaged Power	5	4.5	6
54	32A	Class I UAV – Ducted Fan	4	4	6
55	32B	Lightweight Heavy Fuel Engine	3	4	5

NOTE: 2004 includes the TRA for all 55 technologies. 2005 includes ratings by the IRT as an update to Milestone B. 2009 data includes IRT assessments for 42 of the CTEs; the two remaining 2009 assessments came from prior ratings in 2005 (4 and 7A, denoted with asterisks). Yellow highlights indicate technologies at TRL 5 in 2009. “X” indicates technology that was not assumed. NR means no report.

2005 to 2009 required to mature most of the CTEs to TRL 6 are indicative of the ambitiousness of developing multiple novel technologies from a wide range of technology providers. The highlighted cells indicate CTEs that were still at TRL 5 in 2009.

Most Technologies Had Reached TRL 6 by 2009

By the time the program was significantly restructured in 2009, and six years after Milestone B, most CTEs had reached TRL 6. The 2004 IRT had 13 CTEs rated at TRL 6, and the last IRT assessments in 2009 had 36 of 44 CTEs rated at TRL 6. By 2009, the PM FCS concurred with all the ratings of the IRT, according to IRT briefings. The eight remaining technologies below TRL 6 (plus 7B) were to be further evaluated at the 30-node test that was forthcoming.⁵⁵ For the eight CTEs that were TRL 5 in 2009, the PM had rated all of them as TRL 6 in the prior year.⁵⁶

There Were Lingering Technology Problems from Complementary Systems

The May 2009 IRT also recommended that the “ASA(ALT) should closely monitor the JTRS GMR 30 node test,” the results⁵⁷ of which, from both the 2009 and 2010

⁵⁵ Major Scott Grieg et al., “FCS Technology Readiness Assessment (TRA) Executive Summary,” submitted by Ms. Mary J. Miller, Office of the Deputy Assistant Secretary of the Army (Research and Technology) (no approval signature), May 2009. Not available to the general public.

⁵⁶ Multiple IRTs cover all eight CTEs, which included discrepancies between IRT and PM assessments: February 2009 (includes discrepancies between ratings for 1a, 1b, 3B2, 16A), May 2009 (for 12, 16A, 32B), and June 2008 (for 7A and 4).

⁵⁷ Department of Defense Programs, “JTRS GMR Executive Summary,” no date.

tests, demonstrated difficulty in establishing the network, low data throughput, and low message completion rates. If the program had continued beyond May 2009, it would be difficult to justify an increase in the IRT's previous TRL 5 ratings of JTRS technologies (CTE1A, CTE1B, CTE4, and CTE7A) based on these test results, which would imply that at least four of the CTEs would be less than TRL 6 even in 2011. Of the non-JTRS related CTEs, three were still at TRL 5 at the program's termination in 2009: Rapid Battlespace Deconfliction, Ground Aided Target Recognition, and the Heavy Fuel Engine. Another important criterion, the scalability of the networking concept to 81 nodes, a full-brigade size, was not demonstrated in the E-IBCT DAB,⁵⁸ which only demonstrated a network of 29 static nodes and judged the root cause of mobility problems to be unknown.

The GAO has examined a variety of technology development efforts and noted a correlation between program cost growth and immaturity,⁵⁹ recommending a technology be matured to TRL 7 prior to Milestone B.⁶⁰ The DoD, however,⁶¹ requires CTEs to be at TRL 6 prior to entering the SDD phase at Milestone B. Despite this difference in opinion, FCS has demonstrated the tremendous challenge of maturing several novel technologies simultaneously on an aggressive schedule and with a broad source of technology providers, including complementary programs and the S&T community. Yet at the program's cancellation, the ASA(ALT)'s IRT concluded⁶² that 80 percent (36/44) of the CTEs had matured to TRL 6, starting from 13 CTEs at TRL 6 in 2004. The remaining eight CTEs, which had not reached TRL 6 in 2009, still matured from the start of the SDD period in 2003; of those eight CTEs, four were outside of the FCS program's control, as they were associated with complementary radio programs, like JTRS. Although the maturation of many CTEs proceeded slower than expected by both the program and external observers, the ambitious goals of many of these technologies must be put in perspective.

MANET. The importance of developing an advanced mobile tactical Internet-like network was necessary not only for the FCS concept but also to the wider DoD community as highlighted by the Deputy Under Secretary of Defense for Acquisition and Technology (DUSD(A&T)):

⁵⁸ "Technology and Network Maturity," E-IBCT DAB IPR, January 2011.

⁵⁹ Michael J. Sullivan, "GAO Review of Technology Transition Practice," 4th Annual Acquisition Research Symposium, May 16, 2007.

⁶⁰ General Accounting Office, *Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes*, Washington, D.C.: General Accounting Office, GAO/NSIAD-99-162, July 30, 1999. (The GAO is now known as the Government Accountability Office.) See also Sullivan, "GAO Review of Technology Transition Practice," 2007, which explicitly recommends technologies be matured to TRL 7 prior to Milestone B for MDAP.

⁶¹ Young, "Operation of the Defense Acquisition System," 2008.

⁶² The May 2009 TRA documents 35 of 44 CTEs at TRL 6, and the May 2009 IRT review, although not part of the 2009 TRA, rated one more, CTE7B—Soldier Radio Waveform, also at TRL 6.

The network technologies, including quality of service, mobile tactical networks, and network security continue to be attention areas for the Department. The FCS program continues to be a forcing function in addressing the transition to mobile, reliable network technology to provide timely, accurate, and appropriate situational awareness and understanding to all levels of command.⁶³

All networks must communicate information, successfully delivering it from a source to a destination. Mobile Ad-Hoc Networks rely on wireless communication without a stable underlying wired infrastructure, unlike the Internet, which has nodes that are not mobile and rely on a relatively stable fiber optic and telephony copper wire network as the backbone. Attempting to design MANET network protocols, rules for optimal communication between nodes, is an immensely challenging technical problem. MANET design must also contend with a lack of an information-theoretic foundation that has been fundamental to the success of traditional wireless networks. Although theory does not always translate into practical realizations of a concept, the information theory of MANET would at the least allow for credible limits of information capacity of any one user within the network. In the FCS program, it was rightly designated a CTE for the program, and was predicated on revolutionary technological and fundamental advances.

The challenge of establishing fundamental performance limits of a MANET was highlighted in a 2006 program briefing of DARPA's ITMANET effort to establish information-theoretic results. However, doubts about scaling MANET information capacity to a reasonable number of nodes existed as early as 2000. The DARPA ITMANET program, begun in 2006, convened academic and research lab experts to understand basic MANET capacity limits, network protocols, and relationships between emerging technologies, while acknowledging the ambitiousness of this multiyear undertaking.

The FCS Network, predicated on a MANET implementation, employing ground and air systems as nodes, was thus being designed without a foundation of fundamental results. The fact that such scientific questions, fundamental to the entire conceptual basis of FCS, were being carried out in parallel, and for many years after Milestone B, posed significant risk to the entire program. This risk was acknowledged, however, and thus several technologies, like MANET Protocols and Quality of Service, were designated as CTEs. Although the lack of MANET theory is widely acknowledged, its implications and impediments for practical progress are still debated today.⁶⁴

In addition to the lack of information theory supporting the MANET concept, operational requirements also posed challenges for a practical realization of a tactical

⁶³ Dr. James I. Finley, Deputy Under Secretary of Defense (Acquisition and Technology), testimony before the U.S. House Committee on Armed Services Air and Land Forces Subcommittee, March 27, 2007.

⁶⁴ R. Ramanathan et al., "Scalability of Mobile Ad Hoc Networks: Theory vs Practice," in *Proceedings of MILCOM 2010*, San Jose, Calif.: IEEE, November 2010.

MANET. The JTRS network architecture, in order to comply with National Security Agency (NSA) encryption requirements, would require a mobile node, such as an FCS system or soldier, to be shut down, loaded with a new encryption key, and rebooted prior to joining another subnetwork within the brigade, eliminating a key advantage of MANET radios, since it limited roaming.⁶⁵ Reestablishing communication with mobile nodes (units) was a problem that continued to occur even after the cancellation of FCS, in the E-IBCT program, which adopted FCS network hardware and software for its Network Integration Kit.⁶⁶ There are also significant related challenges to developing Quality of Service (QoS) algorithms that ensure end-to-end delivery of data, which are unique to a MANET, and were thus designated a CTE for the program (CTE5). Complicating the effort to develop QoS was the concurrent design and definition of the FCS Network Architecture, which was incomplete even as of 2008, requiring a QoS Algorithms Demonstration to make several assumptions about key network characteristics.⁶⁷

The challenges of realizing the FCS MANET were discussed by wireless networking experts at the “Science of Networks” conference hosted by RAND Arroyo Center. There were four important conclusions derived from this meeting:⁶⁸

1. The science (i.e., theory) of wireless mobile networks is relatively immature.
2. The relatively small number of mobile, wireless networks of today does not scale well to large size (e.g., hundreds or thousands of nodes passing substantial amounts of data).
3. Unprecedented Army networks must be designed through a series of experiments (i.e., trial and error), which FCS was doing.
4. There is no guarantee an experimentally based developmental approach will result in a satisfactory network design.

A related challenge faced by the FCS network is the lack of available bandwidth to meet the demand of various data required for its level of situational awareness.⁶⁹ For data to flow with reasonable delay (as determined by the application, i.e., voice, video,

⁶⁵ George F. Elmasry, “A Comparative Review of Commercial vs. Tactical Wireless Networks,” *IEEE Communications Magazine*, Vol. 48, No. 10, October 2010, pp. 54–59.

⁶⁶ “Technology and Network Maturity,” E-IBCT DAB, 2011, p. 15. “Soldiers anywhere in the network may lose communications for tens of minutes during and after movement of any Soldiers.”

⁶⁷ Red Lawhern, “M&S V&V QoS Technical Maturity Demonstration,” SDSI IPT, Dave Volle, the Boeing Company, D786-12563-1, signature dated August 22, 2008.

⁶⁸ *RAND Arroyo Center Annual Report 2005: A Campaign-Quality Army*, Santa Monica, Calif.: RAND Corporation, AR-7110-A, 2006.

⁶⁹ Leland Joe and Isaac R. Porche, *Future Army Bandwidth Needs and Capabilities*. Santa Monica, Calif.: RAND Corporation, 2004. See also Figures 3.3 and 3.4 for UA bandwidth requirements by platform and unit.

etc.) in a bandwidth-constrained environment requires state-of-the-art radios able to deliver bandwidth-efficient communications.

The June 2008 IRT⁷⁰ conveyed MANET scalability and stability as an unresolved technical challenge, which requires “intensive Program Management,” to integrate MANET protocols (CTE4) being developed by JTRS, into the FCS network.

Battery Options Conflicted with Technology Trends

Another challenging requirement for FCS was the notion of “silent watch,” which required MGV to power all of the various subsystems including C4ISR, Hit Avoidance (APS, sensors, and tracking radars), and various sensor systems, without power from the main engine for a period of eight (Threshold) to twelve (Objective) hours.⁷¹ To put the difficulty of achieving this requirement in perspective, consider that the FCS Battery Pack, which had to obey weight/volume constraints and simultaneously achieve 20 seconds of vehicle acceleration requiring 180kW, could only provide 2–5 minutes of the required silent watch energy.⁷² As Figure 8.1 shows, the battery options available within the weight and volume constraints fell significantly short of the requisite energy for even two hours of silent watch.⁷³ In fact, a notional design to meet both acceleration (power) and silent watch (energy) requirements would need a battery at least seven times larger in weight and volume than allowed by the MGV physical constraints.⁷⁴ Although the Tank Automotive Research, Development and Engineering Center (TARDEC), through its ManTech battery development and manufacturing program, developed technologies that upgraded the batteries to a 14 percent improvement in energy density, 11 percent improvement in weight, 75 percent improvement in power density, and 63 percent decrease in labor hours needed to produce the cell, no options were available to meet both the acceleration and silent watch requirements,⁷⁵ and a technological revolution would be necessary to meet the requirements.

Attempts to develop hybrid power systems have a long history, preceding even the inception of the FCS program. The DARPA Combat Hybrid Power Systems (CHPS) program was established to investigate hybrid electric power systems that might pro-

⁷⁰ Dr. Larry Delaney, “Independent Review of the FCS Network and Software CTEs,” June 16–20, 2008. Not available to the general public.

⁷¹ ORD, Change 3, April 2003, 2.0.5.1.2: The FCS Manned Combat System must operate in a silent watch (reduced thermal or acoustic signature emissions without use of main engine power) for eight hours (Threshold) and 12 hours (Objective) [ORD 3715].

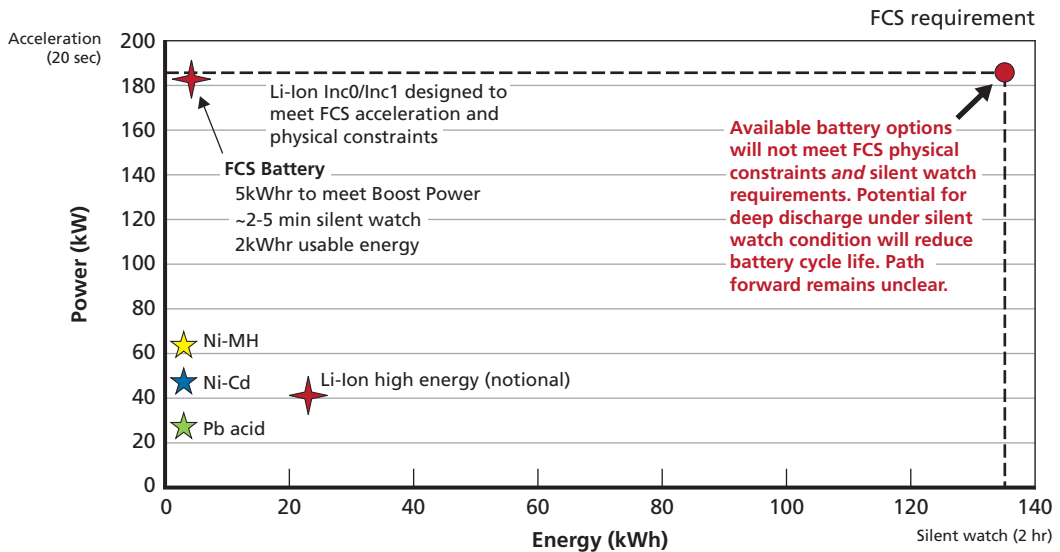
⁷² TARDEC Battery data, Army S&T, no date. Not available to the general public; interview data. See also file[CS_Battery.ppt], no title or author.

⁷³ TARDEC Battery data, Army S&T, no date. Not available to the general public; interview data.

⁷⁴ TARDEC Battery data, Army S&T, no date. Not available to the general public; interview data.

⁷⁵ TARDEC White paper, “TARDEC RTI Input to RAND FCS After Action Review Project,” POC: Steve Olvinik, TARDEC RTI Staff, received by email on May 18, 2011.

Figure 8.1
Energy vs. Power Requirements for FCS MGV Battery Technologies



NOTE: Power = kW → acceleration; Energy = kWh → silent watch.

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vide all the energy and power needs of improved future combat vehicles: specifically the transient, continuous, and pulsed power necessary to drive advanced weapon systems, mobility systems, communications systems, and protective systems.⁷⁶ It used testing strategies that would reappear in the FCS many years later, including a Systems Integration Laboratory (SIL) that replicates the hardware interactions of a true combat vehicle to physically test the CHPS configuration without the full development of a vehicle. This focus on a total systems approach distinguished the CHPS program from existing electric and hybrid electric vehicle programs; it demonstrated for the first time an ability to operate integrated prime power, energy storage, and pulsed power components through a single DC bus with load management while simultaneously supplying realistic, multiple, continuous, and dynamic ground combat vehicle loads. Such a goal would require investigation of various technologies, and those identified by CHPS included advanced batteries, electromechanical pulsed power sources (such as flywheels), advanced prime power units, and high-density power electronics (incorporating advanced materials such as silicon carbide and high-temperature silicon). The program was transitioned to a TARDEC program in 2000 and was renamed the Power and Energy Systems Integration Laboratory (P&E SIL) in 2004 with a goal of develop-

⁷⁶ Marilyn Freeman and Michael Perschbacher, "Hybrid Power: An Enabling Technology for Future Combat Systems," Pulsed Power Conference, 1999. Digest of Technical Papers, 12th IEEE International, June 27–30, 1999.

ing, testing, and integrating hybrid electric power components for a notional manned ground vehicle.⁷⁷ At the program's cancellation in 2009, the CTE associated with lithium-ion batteries, CTE31 (High Density Packaged Power), was at TRL 6.⁷⁸ Despite this legacy of innovation, even in late 2009, "the performance requirements for batteries to meet hybrid military combat are beyond today's state-of-the-art."⁷⁹

There were fundamental challenges associated with realizing a battery capable of the required eight hours of silent watch while respecting the weight and volume constraints. In 2003, however, the Technology Readiness Assessment produced for the Milestone B decision by the ASA(ALT) and approved by DDR&E gave a TRL 5 rating—meaning that the component was validated in a relevant environment.⁸⁰ This rating was based on the assertion that "Lithium-Ion batteries will increase power density allowing reduction in weight and volume while meeting the silent watch requirement," offering a CHPS battery solution able to deliver 30kWhr and tested in a SIL. It is unclear which exact CHPS solution is referred to, but according to a TARDEC report, a CHPS 30kWhr battery pack had a weight/volume of 270kg/500 liters,⁸¹ whereas the MGV physical constraints limited weight/volume to 193kg/126 liters.⁸² More importantly, this battery pack could at best provide two hours of silent watch, only if the power load did not exceed 10kW, but the MGV required a silent watch power load of 50–70kW, effectively reducing the capability to two minutes of silent watch.

TRL Assessments Are Deficient in Ambitious Technology Development

None of the TRAs mention that the state-of-the-art lithium-ion technology can only provide two minutes of silent watch. Interviews with some program officials have indicated that it was not widely known that lithium-ion would not meet the silent watch requirement, and if it had been known, the CTE should have remained at lower TRL levels. Other program officials indicated, however, that the TRL ratings were inadequate, as the TRL methodology does not consider operational requirements and is more "academic" in nature. If the state of the art for all CTEs is not widely known between the various program stakeholders, then expectations for technology development can be unrealistic within cost and schedule constraints. The requirements com-

⁷⁷ Nancy Saxon, Eugene Danielson, and George Frazier, "Update on the U.S. Army TARDEC Power and Energy P&E Sil Program," TACOM/TARDEC #1708, April 2007.

⁷⁸ Grieg et al., "FCS Technology Readiness Assessment (TRA) Executive Summary," May 2009.

⁷⁹ Joseph K. Heuvers, "Energy Storage Commonality Military vs. Commercial Trucks," 20295, TARDEC RDECOM presentation, October 27, 2009.

⁸⁰ See "FCS INC I Tech Readiness Assessment," signed by A. Michael Andrews, April 14, 2003.

⁸¹ Gus Khalil, Eugene Danielson, Edward Barshaw, and Michael Chait, "Power Supply and Integration in Future Combat Vehicles," RTO AVT Symposium on "Functional and Mechanical Integration of Weapons and Land and Air Vehicles," held in Williamsburg, Va., June 7–9, 2004, RTO-MP-AVT-108.

⁸² TARDEC Battery data, Army S&T, no date. Not available to the general public; interview data.

munity should be aware of the technical challenge imposed on the program so that it can perform tradeoffs or adjust requirements if the goals for any technology are overly ambitious. On the other hand, the technology development community should not discount operational requirements in their assessment of CTE maturity. If TRL ratings for CTEs do not account for the operational requirements of systems that employ them, then other metrics, such as Integration Readiness Levels or System Readiness Levels, should be used to assess the maturity of CTEs. As well, the lithium-ion example demonstrated the importance of being able to scale technology demonstrations and testing to levels compatible with eventual requirements, with sufficient time for adjustment of requirements, concepts, and solutions should problems arise.

Software Development Was Very Ambitious

The FCS concept called for a Brigade Combat Team, requiring the network and battle command software to sustain thousands of soldiers and their platforms, each with a multitude of sensors that generated data for situational awareness. Such a strategy imposed many technology challenges, a prominent example of which was the complexity faced by software development.

The GAO⁸³ drew attention to the scope and management of software development. The effort doubled, in terms of lines of code to be written, during the FCS program. The result was a monumental 63 million total lines of code. The Joint Strike Fighter, the next most software-intensive weapon program, needs just a third of this amount, only 19 percent of which, according to Army estimates, was written from scratch, the remainder constituting reused code from other military systems or commercial off-the-shelf (COTS) software.⁸⁴ Previous experience indicates that software-intensive programs are more likely to be successful if they follow an evolutionary environment, which the Army was pursuing with FCS. The software deliverables were spread out in four blocks, each adding incremental functionality in eight areas, which the Army and LSI were further subdividing into 100 smaller and more manageable subsystems.

As an illustration of problems with the rapid acquisition strategy, the GAO⁸⁵ highlights that the last 10 percent of software delivered and tested will be *after* the early 2013 production decision. Other key issues were inadequately defined requirements that could hamper desired functionality, as well as a lack of accuracy in estimating the

⁸³ Government Accountability Office, *Defense Acquisitions: Key Decisions to Be Made on Future Combat System*, 2007.

⁸⁴ Government Accountability Office, *Defense Acquisitions: Key Decisions to Be Made on Future Combat System*, 2007.

⁸⁵ Government Accountability Office, *Defense Acquisitions: Key Decisions to Be Made on Future Combat System*, 2007.

required lines of code (i.e., level of effort), which could be understated⁸⁶ by as much as 70 percent. Even with a robust software engineering process in place, our interviews indicated that the complexity of SoSCOE made coordination among Army engineers working on different portions nearly impossible, and the progress reviews were too detailed to be helpful at a larger functional level.⁸⁷

New Software Approaches Developed During FCS Provided Value

The particular challenges of SoS-level software development evaluation are detailed in a Carnegie Mellon Software Engineering Institute (SEI) report (based upon work done for PM FCS and then PEO-I).⁸⁸ A basic feature highlighted in this report is unforeseen emergent behavior arising from the dynamic interaction of constituent systems in a complex SoS, making it difficult to understand the contribution of any component-level design change, as minimal as it may seem unto itself. The inadequacy of traditional software review approaches for SoS software development, due to the complexity phenomenon, prompted a new methodology to be developed during the program called the “SoS Lifecycle Architecture” (LCA) approach. Overall, the SEI report concludes, the SoS LCA was an effective means of evaluating FCS SoS software, far exceeding other software-specific review events on the program, and helping to discover problem areas and recognizing software packages that were meeting or exceeding expectations. Furthermore, the SoS LCA was able to report technical, cost, and schedule risk at an appropriate level of detail for senior program management to enable the decision-making process. Some of the lessons offered by the report include: building the SoS LCA process in contract provisions from the outset, budgeting 1.5 years prior to the review for planning and executing the process, and maintaining close coordination between geographically and organizationally diverse evaluation team members.

The current Common Operating Environment effort will attempt to carry forth SoSCOE functionality, ensuring compatibility with legacy systems. Despite using software engineering best practices such as the Capability Maturity Model Integration (CMMI),⁸⁹ it is unclear whether the common operating environment (COE) has captured and implemented lessons learned from previous SoSCOE development.⁹⁰

⁸⁶ Government Accountability Office, *Defense Acquisitions: Key Decisions to Be Made on Future Combat System*, 2007.

⁸⁷ Interview data.

⁸⁸ Stephen Blanchette, Jr., Steven Crossen, and Barry Boehm, *Evaluating the Software Design of a Complex System of Systems*, Carnegie Mellon Software Engineering Institute, CMU/SEI-2009-TR-023, January 2010.

⁸⁹ CMMI is a process improvement approach developed by Carnegie Mellon’s Software Engineering Institute to improve large-scale software development processes in various organizations.

⁹⁰ Terry Edwards, “ASA(ALT) System of Systems Engineering Processes,” CMMI Technology Conference, November 16, 2010.

Active Protection System Requirements and Integration Proved Difficult

FCS had a notion of layered survivability (Figure 8.2),⁹¹ in which Active Protection Systems (APS), part of a larger Hit Avoidance Suite (HAS), fall in between the “Don’t be hit” and “Don’t be penetrated” layers. A TARDEC-developed system, the Integrated Army Active Protection System (IAAPS), was identified by FCS as the baseline active protection system for manned ground combat vehicles.⁹² TARDEC claims that it is the most successfully tested APS system in the world: nearly 100 threat defeat demonstrations, dual defeats (two threats in the air simultaneously), and the only system to have defeated four separate classes of threat munitions.⁹³ Although foreign ground forces have claimed to operationally demonstrate APS, such as the Israeli Defense Force’s trophy,⁹⁴ FCS viewed this particular system as an engineering developmental model that had not been operationally proven at the integrated system level.⁹⁵

Changing requirements led to problems integrating IAAPS on the rooftop of the vehicle, which was precious real estate for other non-APS equipment, resulting in FCS abandoning IAAPS in 2006 to begin development of a vertical launch “pop and pitch” APS.⁹⁶ The Active Protection System development and integration was subcontracted to Raytheon in 2006 by BAE Systems, who led the Hit Avoidance Integrated Product Team for MGV.⁹⁷ TARDEC Engineers provided oversight and technical guidance to MGV One Team Partners throughout the development of the Hit Avoidance Suite but determined that the APS developer selected immature technologies for integration on the MGV despite performing multiple trade studies.⁹⁸ At cancellation of the program, the Short-Range and Long-Range Interceptor were significantly larger, more complex, and more expensive than originally planned because the system had not been testing against an appropriate range of threats nor matured the proposed technologies.⁹⁹ The constantly evolving vehicle design, and the corre-

⁹¹ Heather Molitoris and Daniel Hicks, “System Engineering Approach to Assessing Integrated Survivability,” TARDEC, no date. See also Steve Knott, “Ground System Survivability Overview,” TARDEC, no date.

⁹² TARDEC White Paper, “TARDEC RTI Input to RAND FCS After Action Review Project,” 2011.

⁹³ TARDEC White Paper, “TARDEC RTI Input to RAND FCS After Action Review Project,” 2011.

⁹⁴ Yaakov Katz, “Israel Exercises Trophy and Iron Fist Active-Protection Systems,” *International Defence Review*, November 2, 2010.

⁹⁵ Major General Jeff Sorenson, “Combat Vehicle Active Protection Systems,” testimony before the U.S. House of Representatives, Subcommittee on Tactical Air and Land Forces, September 21, 2006.

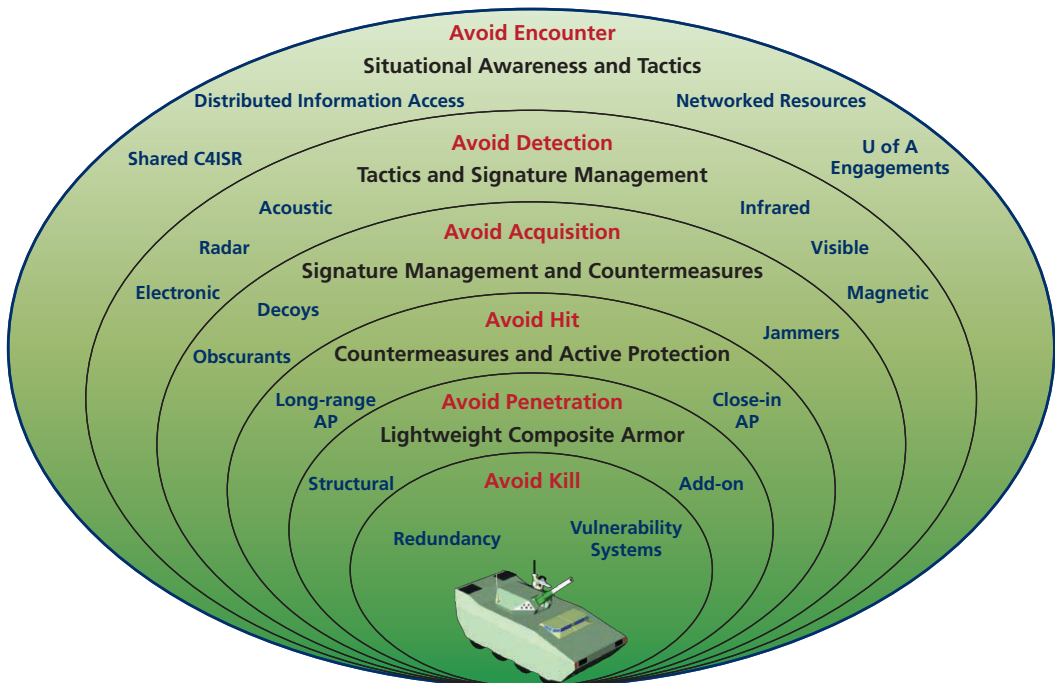
⁹⁶ Sorenson, 2006.

⁹⁷ BAE Systems, “BAE Systems Awards Contract to Raytheon to Develop Active Protective Subsystem Supporting Hit Avoidance Program for FCS Manned Ground Vehicles,” Santa Clara, Calif., April 25, 2006.

⁹⁸ TARDEC White paper, “TARDEC RTI Input to RAND FCS After Action Review Project,” 2011.

⁹⁹ TARDEC White Paper, “TARDEC RTI Input to RAND FCS After Action Review Project,” 2011.

Figure 8.2
FCS Holistic Approach to Survivability, the “Onion Skin”



RAND MG1206-8.2

sponding SWaP constraints, also made it nearly impossible to integrate the APS solution onto the platform.¹⁰⁰

A further complication faced by any APS development is the collateral damage possibilities to soldiers and noncombatants from the explosive countermeasures, requiring corresponding tactics, techniques, and procedures (TTP) for proper usage.¹⁰¹

Despite demonstrations of single and dual munitions intercepts, there was significant skepticism about the effectiveness of Active Protection Systems against kinetic energy munitions, as required by the ORD.¹⁰² An IDA analysis concluded, “it is unlikely that an effective active protection system will be developed against kinetic-energy weapons with velocities over 1,000 m/s.”¹⁰³

¹⁰⁰TARDEC White Paper, “TARDEC RTI Input to RAND FCS After Action Review Project,” 2011.

¹⁰¹TARDEC White Paper, “TARDEC RTI Input to RAND FCS After Action Review Project,” 2011.

¹⁰²Operational Requirements Document (ORD) for the Future Combat Systems Section 2.2.6, prepared by UAMBL, Fort Knox, Ky., Change 3 (JROC Approved) April 14, 2003. Not available to the general public.

¹⁰³Cynthia Dion-Schwarz, Leon Hirsch, Phillip Koehn, Jenya Macheret, Dave Sparrow, *FCS Vehicle Transportability, Survivability, and Reliability Analysis*, Alexandria, Va.: Institute for Defense Analyses, D-3100, April 2005.

Technology Goals Were Ambitious and Capabilities Were Slow to Develop

Thus far, we have discussed the novelty of only a few of the technologies undertaken by FCS. The most important of these, called CTEs, were essential for the 18 systems of the SoS concept. The rates at which these technologies developed were slower than most expected, but the challenges must be put in context with the ambitious technology goals such as developing a tactical MANET, energy sources for MGV, active protection systems, and large-scale software development. The ASA(ALT)'s primary mechanism to assess technology maturity, the IRT, reviewed the TRL ratings and rationale provided by the PM and LSI's TMA, disagreeing at times with those ratings to produce a TRA for the Army and DoD's Acquisition Executives. At the program's cancellation in 2009, the IRT judged that 36 of 44 CTEs were a TRL 6, the level required to enter SDD and pass Milestone B per DoD guidelines. FCS was able to make significant progress in technology development, although at a slower pace than initially expected. Even if the program had not been cancelled, there would have remained challenges to mature the remaining CTEs to TRL 6, and eventually mature all CTEs to TRL 7 for Milestone C per DoD guidance. These challenges arise not only from the novelty of the CTEs, but also the program's reliance on a broad range of external sources for technology solutions.

This section only scratched the surface of just how revolutionary the FCS technologies would have been. Our discussions with senior engineers in the FCS program highlighted many other examples of profoundly aggressive technology choices to meet difficult requirements. These choices were slowly being shown to be unfeasible, and difficult trades were enacted to reset the program.

The Broad Range of Technologies in the FCS Program Relied on Complementary Programs and Use of S&T Base

The complexity of the FCS SoS required the integration of several technologies in other programs or in the S&T community to be developed concurrently with the FCS program. We have discussed the novelty of systems and CTEs in the previous section, and how many of them were ambitious goals surpassing the state of the art. In this section we consider the interaction between the FCS program and external programs or S&T efforts to realize the SoS and the multitude of novel technologies.

Concurrent technology development requires coordination and synchronization, which can be enforced through program management practices when developers are internal to the program construct, but is more elusive if several programs, each with its individual mandates and budgetary constraints, are required to coordinate design activities to produce compatible technological solutions. We examine the FCS interaction between essential external programs, which were required to develop technology that was critical for the SoS, to identify lessons for future acquisitions that will require

interprogram coordination. Additionally we consider the impact of FCS on the S&T base, which as the modernization strategy articulated¹⁰⁴ would be essential to realizing the fundamentally different CONOPS and system characteristics, and as such would need to quickly refocus its efforts to deliver the Objective Force in the shortened timeline.

Complementary Programs List May Have Been Overly Complex

The Defense Acquisition University's *Defense Acquisition Guidebook* states that the technology development strategy should identify any dependencies on planned or existing capabilities of other programs or systems.¹⁰⁵ In addition, as part of the periodic reporting requirements for MDAP, a Defense Acquisition Executive Summary (DAES) chart must include an interrelationship, dependencies, and synchronization with complementary systems as part of the monthly brief.¹⁰⁶ The FCS technology development strategy describes two sources of capabilities essential to mission accomplishment but external to PM direct control: complementary and associate programs.¹⁰⁷ Complementary programs (CPs) are essential for the FCS SoS to meet the KPP articulated in the ORD, whereas associate programs¹⁰⁸ are existing technologies that FCS must interoperate with, but not as essential as CPs for SoS functionality.

In 2006 there were 170 complementary and associate programs listed in the FCS contract,¹⁰⁹ but this number is not consistent across program documentation and changed over time.¹¹⁰ Most program officials agree, however, that only a few of the stated CPs were truly critical to the success of FCS. Of the 170 CPs, only 32 are directly relevant to an FCS system or the network, as shown in the embedded systems band of Figure 8.3.¹¹¹ Program officials further expressed that the selection of a CP was a seem-

¹⁰⁴"2001 Army Modernization Plan," 2001.

¹⁰⁵It should be noted that many of the lessons learned from the FCS program and mentioned in this document led to changes in DoD regulations. A case in point is a set of updates to DoD 5000.2 which in 2008 drives complementary programs and certain technologies to be prototyped and proven before program are designed to implement them. *Defense Acquisition Guidebook*, July 29, 2011, Defense Acquisition University (DAU), Section 2.2.5.

¹⁰⁶*Defense Acquisition Guidebook*, Section 10.9.4.

¹⁰⁷Technology Development Strategy Rev. C, dated February 28, 2004. Associate programs are those that FCS must interoperate with as described in the ORD and C4 Integration Support Plan.

¹⁰⁸PM FCS BCT, Submitted by Maj. Gen. Charles Cartwright, "Acquisition Strategy Report, Revision 2, Future Combat Systems," 2008. Not available to the general public.

¹⁰⁹As defined in attachment 11 of the FCS contract. Tina Vu, *Annex I Complementary Programs to Future Combat System (Brigade Combat Team) Supportability Strategy Data Product DP025*, Document Number D786-10025-9, Rev. H, June 2, 2006.

¹¹⁰Two other lists of CP, from earlier and later in the program, can be found in the appendix to the 2006 contract. Vu, 2006.

¹¹¹Vu, 2006.

Broad Agreements with Army S&T and Other PEOs Enabled Technology Development

Various contractual agreements were generated between the PM, LSI, and a CP to deliver technologies to FCS. As of December 2008 there were 125 MOAs between various Army PEOs and CPs, as shown in Table 8.3.¹¹⁶ Some of these PEOs had additional specificity in the form of a subordinate memorandum of agreement (SMOA), such as the eight for PEO intelligence, electronic warfare, and sensors (IEW&S), detailing deliverables to the LSI including: contract data requirements list, data accession list, interface control document, source code for message exchange, and user/training manuals. Despite the use of such program management practices to ensure coordination and synchronization between FCS and CPs, the GAO found that of the 500 interface control documents, only 61 were completed as of late 2007, and 261 were expected to be completed by 2009 PDR.

The Acquisition Strategy Report (ASR) recognizes the challenge of relying on various CPs and that cost, schedule, and technical performance of CPs will directly impact corresponding factors in FCS.¹¹⁷ However, the ASR also states that each CP “represent[s] an opportunity for the FCS program to meet the requirements of the SoS specification with less cost, faster schedule, and less risk.”¹¹⁸ This inherent dichotomy—that complexity in choice of CPs somehow would reduce cost/schedule/risk—

Table 8.3
MOA and SMOA Between PEOs and CPs

PEO	MOA	SMOA	Num CPs
AMMO	1	0	12
AVIATION	1	0	10
C3T	1	0	23
CS&CSS	1	5	19
DISA	1	0	1
EIS	1	0	6
GCS	1	0	4
IEW&S	1	8	12
JPEO CBD	1	0	8
LTA	1	0	1
NAVY	1	0	1
Soldier	1	2	5
STRI	1	3	13
Missiles and Space	1	4	9
USAF	1	0	1
Totals	15	22	125

¹¹⁶ Spreadsheet of MOA and SMOA retrieved from ACE by POC. Not available to the general public.

¹¹⁷ PM FCS BCT, “Acquisition Strategy Report, Revision 2, Future Combat Systems,” 2008.

¹¹⁸ PM FCS BCT, “Acquisition Strategy Report, Revision 2, Future Combat Systems,” 2008. .

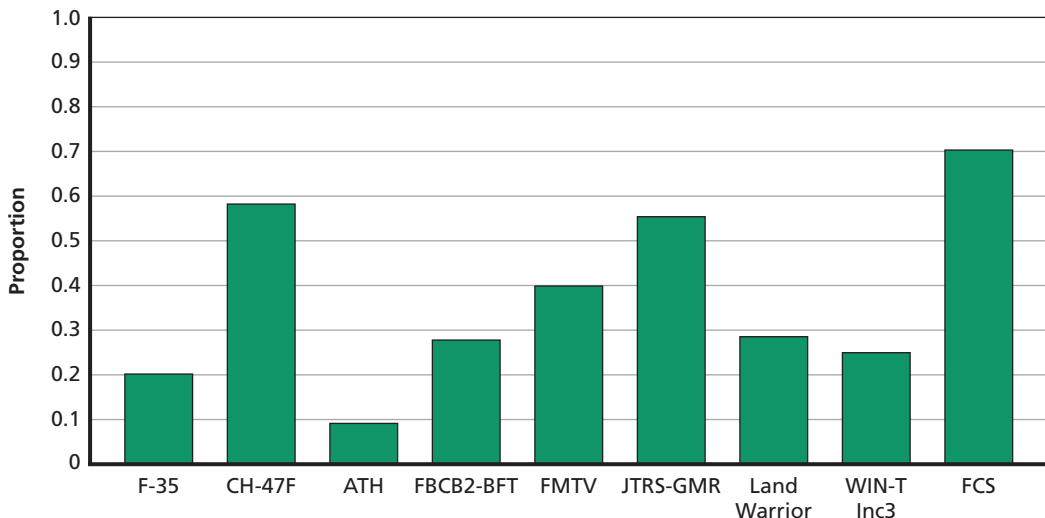
was pervasive in the program, but remained unproven in 2009 when the program was cancelled.

FCS Program Focused on “Future” Programs

In addition to the large number of CPs necessary for FCS to achieve its operational requirements, the program took on further risk by relying on future capabilities rather than fielded CPs. By examining the DAES charts for various MDAPs, we see that 70 percent of the CPs considered essential for FCS were future capabilities¹¹⁹ (Figure 8.4). A closer look at the complementary systems, shown in Table 8.4, shows how 20 complementary systems changed over a few years of the program. Of the 20 systems listed, 8 remained stable, 4 became more risky over time, 2 became less risky over time, 4 were removed from assessment, and 2 got more and then less risky over time.

One recommendation by program officials is that the Army should not be swayed by the promises of external programs, especially those being concurrently developed.¹²⁰ Challenges that arise by depending on future capabilities are exemplified by JTRS,

Figure 8.4
Proportion of CPs That Are Future Capabilities in Various MDAPs



SOURCE: Data compiled and analyzed by study team from program SARs.

RAND MG1206-8.4

¹¹⁹The data are from a single DAES chart for each program, which is required to produce them monthly. The FCS DAES chart only shows 18–20 CPs over a period of a few years of the program, from which we infer these CPs to be more essential than the other 150 CPs mentioned in the ASR.

¹²⁰Interview data.

Table 8.4
Risks from Interfacing with Complementary Systems

Complementary System	Future/Current	June 2007	Dec 2007	June 2008	Dec 2008	April 2009	June 2009
JTRS-GMR	Future	2	2	2	2	2	2
JTRS-HMS	Future	2	2	2	2	2	2
JTRS-AMF	Future	1	2	2	2	2	2
WIN-T	Future	2	2	2	2	2	2
FBCB2	Current	1	1	1	1	1	2
DCGS	Future	1	1	1	1	1	1
NCES and NECC	Future	1	1	1	1	1	1
OneTess	Future	1	2	2	2	2	2
OneSAF	Current	1	1	1	2	2	1
JLSCAD-Air*	Future	2	3				
JLSCAD-Ground	Future	2	2	1	1	1	1
JCAD	Future	1	1	1	1	1	1
JWARN	Future	1	1	1	1	1	1
ASTAMIDS	Future	2	2	2	2	2	2
GSTAMIDS	Future	1	2				
SAR/GMTI	Future	2	2	1	1	1	1
Excalibur	Current	1	2	2	2	1	1
MRM	Future	1					
SAAS	Future	1	1				
GSS	Future			1	1	1	1

NOTE: Risk coding based on DAES reports from given year; three = irresolvable issues; 2 = resolvable interface issues; 1 = no known issues. No number indicates removal from assessment.

both a complementary program and a critical technology upon which the fate of FCS rested.

The FCS experience has shown the difficulty of managing overall program and technical risks posed by numerous CPs, which could only be influenced to a limited degree by the lack of joint requirements. As an illustration of this challenge, consider the example of using a JTRS radio to teleoperate a SUGV so that it can provide real-time ISR to decision makers.¹²¹ An Army research lab (ARL) experiment concluded that the implementation of the JTRS radio provided by the FCS Network Analysis and Integration Group “does not appear ideal for teleoperation of robotic systems.”¹²² Teleoperation is a requirement for FCS, and without a corresponding requirement for JTRS radios, it will be difficult to influence design decisions to guarantee technologically compatible solutions. However, enforcing consistent joint requirements between complementary programs is much more challenging in a system of systems.

¹²¹ Barry O’Brien and Jesse Kovach, *Future Combat Systems (FCS) Small Unmanned Ground Vehicle (SUGV) Teleoperation Experiment Results*, Adelphi, Md.: ARL, ARL-TR-4660, December 2008.

¹²² O’Brien and Kovach, 2008.

For example, the JTRS requirements did not explicitly include environmental issues faced in vehicles, but instead the JTRS ORD had a temperature requirement that was inconsistent with the next higher level (FCS MGV) ORD in the SoS sense. Efforts to ensure that radios do not overheat in the MGV environment add size and weight to the electronics,¹²³ burdening an already difficult weight-reduction challenge for FCS transportability requirements.

Such problems illustrate how CPs, which enable SoS functionality, demand requirements to be generated and analyzed in a coherent fashion, as well as a technology development strategy that allows flexibility in the design process. This is executed in multiple possible ways, all predicated on having flexibility in requirements and concepts as well as the time to adjust and adjudicate follow-on ramifications from changes. In the case of FCS, if a CP were ahead of schedule compared with FCS, then the FCS requirements and concepts would have to adapt to the eventual outcome. If it were behind FCS, the program would have to adjust to live within the parameters. For highly coupled programs, like JTRS and WIN-T with FCS, major changes will severely affect the overall FCS concept and ability to meet requirements. Thus, it is paramount to have plans for those contingencies.

If a thorough technical analysis of program requirements determines that a CP cannot deliver a solution with its existing design, then either the program must fund the CP to generate a new design and prototypes or assume the technology development responsibility itself. Yet the possibility of such a thorough analysis is predicated on the availability of technical information from a CP, which our interviews indicated was a challenge as FCS struggled for the first two to three years to understand the status of JTRS.¹²⁴ Furthermore, the ORD specified JTRS as the primary radio for FCS, discouraging analysis of alternative radios that, although perhaps less capable, may have provided some fraction of desired operational capabilities. As a result, FCS was wholly dependent on the JTRS radio to create the network that would enable the SoS to provide the requisite situational awareness. Future acquisitions must ensure that any CTE provided by a CP have an internally funded program alternative to hedge the possibility that design changes or schedule synchronization may not be influenced by program management constructs. Even a cursory cost analysis, carried out during the requirements generation phase, of such an internally funded alternative will reveal if such a hedging option is viable within the program's budget, and if not, at least motivate a thorough technical compatibility analysis from the SoS perspective before assuming complete dependence on the CP.

¹²³Government Accountability Office, *Restructured JTRS Program Reduces Risk, but Significant Challenges Remain*, Washington, D.C.: Government Accountability Office, GAO-06-955, September 2006.

¹²⁴Interview data.

FCS Relied Heavily on Army S&T

The Army modernization strategy relied on its S&T base to enable timely fielding of the Objective Force, with a mandate to make FCS “the Army S&T community’s unconditional highest priority.”¹²⁵ The program also directly influenced the selection of technology objectives to be prioritized and funded, creating a perception within the S&T community that any effort not linked to the FCS concept would be less likely to continue or begin, but also positively affecting the S&T base by providing increased resources and visibility. Resources within S&T were thus primarily allocated toward supporting FCS with agreements to transition-specific technologies from the Research, Development and Engineering Centers (RDECs) to the PM/LSI. In many of the critical technology areas, particularly survivability and lethality, the S&T base provided leading expertise, but in other areas it would need to compete with the LSI’s proclivity for industrial sources of technology, causing disenfranchisement within the research community. The importance of a strong Army S&T base for assessment of technical performance and drivers of technology for weapon system development has been acknowledged¹²⁶ and provides the impetus to consider the impact of Army modernization, through FCS, on this community.

Technology transfer from research institutions like DARPA and Army S&T to programs of record under PM FCS and the LSI can be challenging for a variety of reasons, including differing organizations, development processes, and definitions of success. Further complicating this transfer was an aggressive schedule resulting from the significantly reduced timeline of the combined “concept design” and “concept and technology demonstration” phases. Pulling in Milestone B from 2006 to 2003 allowed only half the time required for technology development in an already technically ambitious program. In the end, the shortened development cycle precluded almost any technology development ahead of Milestone B, thus leaving it for the SDD phase of the program.

The reliance on S&T to field the Objective Force arose even before commencement of the official program of record, as a 2002 S&T IPT presented the top 15, from a collection of 40, S&T programs, which were reviewed with preliminary TRL and engineering manufacturing readiness levels and presented to Major General Yakovac, the PEO(GCS).¹²⁷ These S&T products were also prioritized by need and categorized

¹²⁵“2001 Army Modernization Plan,” 2001.

¹²⁶John Lyons, Richard Chait, and Duncan Long, *Critical Technology Events in the Development of Selected Army Weapons Systems: A Summary of ‘Project Hindsight Revisited,’* NDU Center for Technology and National Security Policy, September 2006.

¹²⁷Ed Brady and Dr. Bradas, co-chairs S&T IPT, “Technology Transition Assessment UoA Block 1,” Presented to Major General Joseph Yakovac, PEO GCS, September 5, 2002. Not available to the general public.

by technological domain, as shown in Figure 8.5.¹²⁸ As expected, most of the S&T demand is for advanced networking.

FCS, as the Army's primary modernization program, greatly influenced the direction of S&T efforts by supporting those efforts that could be directly applied to the program's needs. In April 2004, the Spiral Development and Technology Planning IPT led a series of reviews for proposed science and technology objective (STO) programs, with recommendations for the PM Unit of Action to endorse some and not others.¹²⁹ These endorsements were also affected by discussion that took place during the TRADOC Futures Center STO Review in May 2004.¹³⁰ These STOs fell under the management of various Army labs and commands, including ARL, CERDEC, and TARDEC.¹³¹ Of the 48 STOs under review, 25 were positively endorsed. The technologies embodied by the selected STOs included: networking, robotic control, hit avoidance, power generation for vehicles, chemical sensors, and mine detection and neutralization. In late 2005, a review of existing and new Army technology objectives (ATOs)¹³² was presented, presumably for further investment or interaction. These

Figure 8.5
Early Assessment of S&T Efforts by FCS S&T IPT

EMRL score	Program	TRL score
0.6	Log C2/Agile Commander	6.0
1.7	OFW	5.9
N/A	Close-In APS	5.8
0.9	BTN	5.7
1.1	CAT	5.7
1.6	IDS	5.6
1.2	FCS Engine	5.4
1.5	PGMM	5.1
1.1	Ballistic Armor	5.1
1.3	SUAV	5.1
1.7	Coalition Combat ID	4.7
1.0	MOSAIC	4.4
1.6	MFS3	4.1
0.5	CHPS	3.9
XXX	Netfires	XXX

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¹²⁸Brady and Bradas, 2002.

¹²⁹"FCS LSI Recommendations for FY05 STO Proposals," May 14, 2004. Not available to the general public.

¹³⁰"FCS LSI Recommendations," 2004.

¹³¹Inferred from those STO program numbers easier to decipher.

¹³²"Review of FCS ATOs," Army S&T, October 2005. Not available to the general public.

ATOs were integrated into technology categories and analyzed for potential products and payoffs. The breadth of the review again implies the program's continual reliance and influence on the S&T base to provide and meet its ambitious goals of developing critical technologies.

In order to ensure productive interaction between PM FCS and the S&T base, primarily managed by Research, Development and Engineering Command (RDECOM), several Technology Transition Agreements were generated to articulate responsibilities of parties, potential deliverables, and a schedule for these milestones. A TTA provides a program, and the acquisition community in general, a tool to extract technology solutions from the S&T base. For example in FCS, UAV systems are a key ISR asset, yet the program lacked a compatible radar technology capable of penetrating foliage. Thus a TTA was generated between CERDEC Intelligence and Information Warfare Directorate (I2WD) and PM FCS¹³³ to transition an ISR radar for the Class IV UAV, from the ARTEMIS (All-terrain Radar for Tactical Exploitation of MTI and Imaging Surveillance) ATO-Demonstration S&T effort. The TTA draft from May 2007 requires CERDEC to deliver the following to FCS: a lightweight all-weather and all-terrain airborne radar compatible with near-term planned UAV (such as the Fire Scout, which was the basis for the Class IV UAV), and a computer model of the radar for simulation. Various status and testing reports, technical metrics for the ATO demonstration, and a schedule for these deliverables are also articulated in the agreement.

The urgency of leveraging technology from the S&T base is exemplified as early in the program as March 2004, when nine TTAs were projected for signature and five potential TTAs were under consideration,¹³⁴ indicating a relatively early adoption of these agreements as a means to formalize interactions between the program and S&T. The nine TTAs projected for signature by the end of March 2004 were linked to critical technology elements, which are by definition critical to SoS functionality and novel technologies, which justify the outreach to the S&T base for procurement or implementation. The other five TTAs under consideration awaited ongoing trade studies or were circumscribed by alternative agreements, such as a SMOA.¹³⁵

In Appendix D we summarize the various TTA in terms of the S&T command furnishing the deliverables and, if applicable, the critical technology element it would support. In some cases, the TTA explicitly mentions that no direct critical technology is identified and that rather an official risk will instead be mitigated.

The modernization mandate to make FCS the unconditional priority for Army S&T required resources to be allocated toward research efforts that could directly sup-

¹³³TTA between ARTEMIS STO and PM FCS. Not available to the general public.

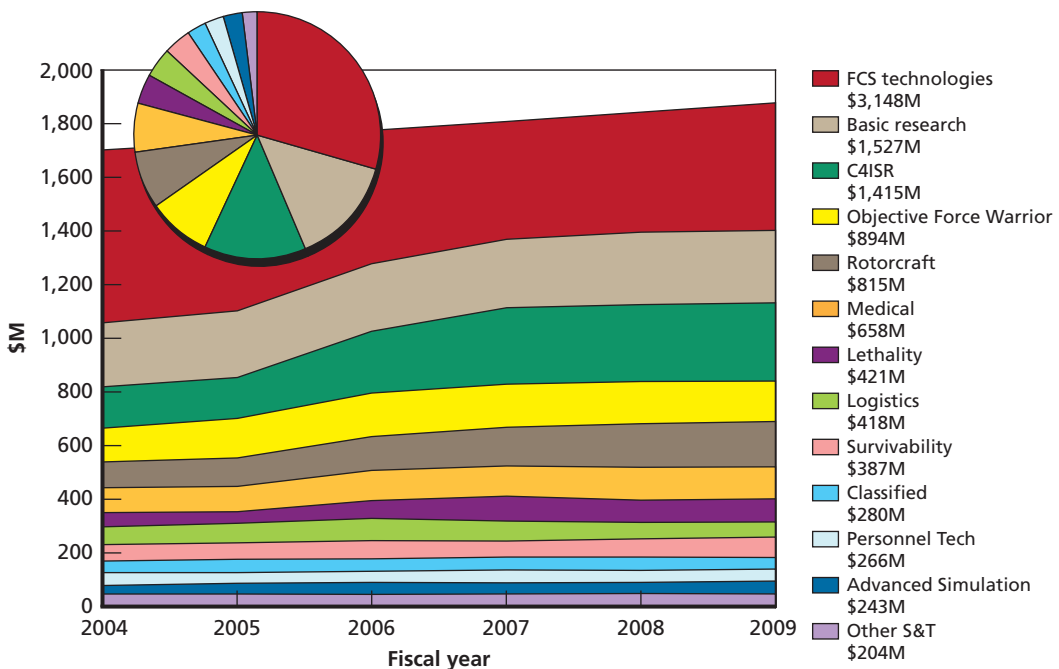
¹³⁴"S&T Technology Transitions to FCS," presentation, March 2004. Not available to the general public.

¹³⁵"S&T Technology Transitions to FCS," 2004.

port the program. The FY04–09 S&T budget displayed in Figure 8.6¹³⁶ shows the relative investments amongst the research portfolio, and it clearly signals adherence to the strategic decisions of prioritizing FCS to achieve the goals of Army modernization. However, as with any portfolio allocation, a balance must be struck between near- and far-term objectives. With the emphasis on supporting the operational needs of the Global War on Terror (GWOT) arising during the FCS program, the S&T portfolio would have to focus on current threats such as IEDs. An opening letter from DASA(R&T) and the ASA(ALT) in the 2007 Army S&T Master Plan¹³⁷ states that

The U.S. Army’s largest S&T investments are in force protection technologies to detect and neutralize IED’s . . . Other important technology investments include command, control, communication, information, surveillance, reconnaissance, lethality, Soldier System, unmanned systems, logistics, and advanced simulation.

Figure 8.6
Army S&T Budget Allocation Showing Prioritization of FCS Technologies



SOURCE: Army Science and Technology Master Plan, Executive Summary, 2007, Office of the Deputy Assistant Secretary of the Army for Research and Technology.

RAND MG1206-8.6

¹³⁶Dr. Thomas Killion, “Army Science & Technology for FCS,” January 27, 2004. Not available to the general public.

¹³⁷“Army Science and Technology Master Plan, Executive Summary,” Office of the Deputy Assistant Secretary of the Army for Research and Technology, 2007.

The shift in emphasis of the \$1.7B requested for S&T in the FY07 presidential budget, from C4ISR and other related technologies previously prioritized to enable FCS to force protection, emphasizes the constant rebalancing of resources required to address fluctuating current operational needs. This challenge to leverage further-term S&T in the face of resource reprioritization toward near-term research will continue to challenge acquisition programs reliant on future force concepts.

Our interviewees have generally concurred that FCS was beneficial for the S&T community because it gave considerable attention to their achievements and future potential and provided a tremendous influx of resources. However, the S&T community might have “overpromised” on some technology developments, but this was RDEC-specific. Given the mandate to deliver the Objective Force in a timely manner, it should be expected that challenges for certain S&T efforts may be cast more optimistically despite the ambitious goals for novel technologies and the aggressive schedule to deliver solutions. On the other hand, some capabilities that were resident in Army S&T, such as sensor technologies, were not fully leveraged by FCS due to untenable cost expectations for requisite capabilities.¹³⁸ According to many we spoke with, the LSI’s proclivity to rely on industry to produce better and cheaper technological solutions disenfranchised the S&T community. There are some capabilities, particularly in the area of survivability and lethality, that are not widespread in commercial development due to their primarily military applications. In contrast, some capabilities, particularly in the networking and software realm, were stronger in industry, but knowledge increased considerably over the course of FCS within the Army.

Risk, Testing, and Other Technology Development Processes Added to the Complexity of the Program

Developing a comprehensive risk mitigation strategy is critical to a successful defense acquisition program¹³⁹ and is consequently expected from all MDAPs.¹⁴⁰ Similarly important to any program is a test strategy, which articulates what and how requirements or capabilities can or cannot be evaluated experimentally. Additionally, all modern programs exploit modeling and simulation (M&S) or analysis capabilities to validate requirements, CONOPS, and system designs, which either cannot be evaluated through experimentation or would impose too great a cost or schedule burden. All

¹³⁸Interview data: The program wanted to develop sensors covering the entire electro-optical spectrum, including, infrared, for the APS Multi-Function radar for \$100,000 per unit, which was considered by program officials we spoke with to be too low an amount for available implementations.

¹³⁹Defense Acquisition University, *Risk Management Guide for DoD Acquisition*. Sixth edition, v. 1.0, August 2006.

¹⁴⁰*Risk Management Guide for DoD Acquisition*, 2006.

these activities were supported by the organizational structure of FCS program management, which developed plans and executed these practices with mixed success. The complexity inherent to the SoS nature of the program and novelty of numerous CTEs contributed significantly to challenges faced by each of these traditional activities.

Risk Mitigation Methods and Tools Did Not Have the Capability to Address FCS Complexities of Resource Allocation

Traditional risk management has focused on a single system, and unfortunately there are no existing best practices for risk management tailored for the greater complexities of SoS acquisition.¹⁴¹ However, every MDAP must establish a risk management process, which is detailed in the risk management plan (RMP).¹⁴² This process and key program risks are also summarized in the technology development strategy, which additionally describes how funding, schedule, and performance are balanced and traded to manage and mitigate risks.¹⁴³ Further details on mitigation plans for the technology development phase are included in the systems engineering plan¹⁴⁴ (SEP).

FCS developed a RMP with a focus that changed from risk planning and avoidance in the CTD phase¹⁴⁵ to risk assessment and mitigation in the SDD phase.¹⁴⁶ Given the ambitious nature of FCS, in terms of both a drastic departure from traditional Army CONOPS and the development of revolutionary technologies for integration in a complex SoS, risk management at every level of the program would be not only required but essential. The RMP¹⁴⁷ includes the following:

- Roles for risk evaluation and mitigation
- Methods for identifying, analyzing, and prioritizing risk
- Methodology for rating, documenting, and tracking risk
- The process for risk evaluation and mitigation
- A plan for risk management training.¹⁴⁸

¹⁴¹ Rita Creel and Bob Ellison, *System-of-Systems Influences on Acquisition Strategy Development*, Carnegie Mellon University, 2008.

¹⁴² Guidance for risk management is provided by the *Risk Management Guide for DoD Acquisition*.

¹⁴³ *Defense Acquisition Guidebook*, Section 2.2.7, "Risk and Risk Management."

¹⁴⁴ *Defense Acquisition Guidebook*.

¹⁴⁵ Department of the Army, Program Manager, Future Combat Systems, *Future Combat Systems Risk Management Plan*, Revision H, D786-10015-1, June 11, 2004, Appendix B. .

¹⁴⁶ Department of the Army, Program Manager, Future Combat Systems, *Future Combat Systems Risk Management Plan*, Revision H, June 11, 2004, Appendix C.

¹⁴⁷ The RMP defines risk as an event (condition) that has a realistic likelihood of occurring and with an unfavorable consequence.

¹⁴⁸ Department of the Army, Program Manager, Future Combat Systems, *Future Combat Systems Risk Management Plan*, Revision H, June 11, 2004.

Although the PM is ultimately responsible for risk management, day-to-day activities are also managed by various organizations, including IPT's, the Risk Working Group, and the Risk Review Board.

The risk management process begins with planning, resulting in the RMP, followed by identifying, assessing, handling, and monitoring.¹⁴⁹ Various software applications were used for these tasks across geographically distributed stakeholders. The Active Risk Manager (ARM), an ACE-based proprietary risk management application, was the primary tool used from August 2004 on, although RiskControl, an application developed by Boeing, was also used to support this process.¹⁵⁰ Leaders of the IPTs are responsible for identifying potential risks by surveying team members involved in day-to-day technical, cost, and scheduling aspects of the program, and then recording the risk with an initial rating for likelihood and consequence for schedule, cost, and performance impacts.

Likelihood, or the chance the risk event will occur, is based on qualitative data, whereas consequence, or the unfavorable result of the risk event, can be assessed using either qualitative or quantitative data. Likelihood and consequence are reported from a level of 1 to 5 on the "risk grid" (i.e., a matrix grid), which are then converted to risk levels: low, medium, and high. Reported risks are then validated and prioritized by the Risk Working Group, for IPT-level risks, or the Risk Review Board, for program-level risks, and if approved, require a supporting risk assessment to finalize the likelihood and consequence ratings along with a classification into cost, schedule, technical, or program categories.

Handling identified risks consists of choosing one of four methods accompanied by a schedule and budget to accomplish the required tasks. The four methods are avoidance, transfer, assumption, and mitigation. Avoidance seeks a lower risk solution by changing concepts, requirements, or specifications. Transfer is the reallocation of risk to another part of the program, perhaps to another IPT with greater resources or more control over factors influencing the risk. Assumption is the conscious decision to accept the risk, which requires identifying resources necessary to overcome the risk that materializes and ideally setting aside schedule and cost reserves. Mitigation is defined as actions needed to lower the likelihood and consequence and requires developing a detailed plan and monitoring, usually by the IPT.

There were 1,017 risks residing in the Active Risk Manager database at the end of 2009, most of which were closed due to mitigation or irrelevance.¹⁵¹ The types of risk identified in ARM included technical, schedule, and cost, and were further cat-

¹⁴⁹ Department of the Army, Program Manager, Future Combat Systems, *Future Combat Systems Risk Management Plan*, Revision H, June 11, 2004, Section 4.

¹⁵⁰ Department of the Army, Program Manager, Future Combat Systems, *Future Combat Systems Risk Management Plan*, Revision H, June 11, 2004,.

¹⁵¹ Compiled from data provided to the study team.

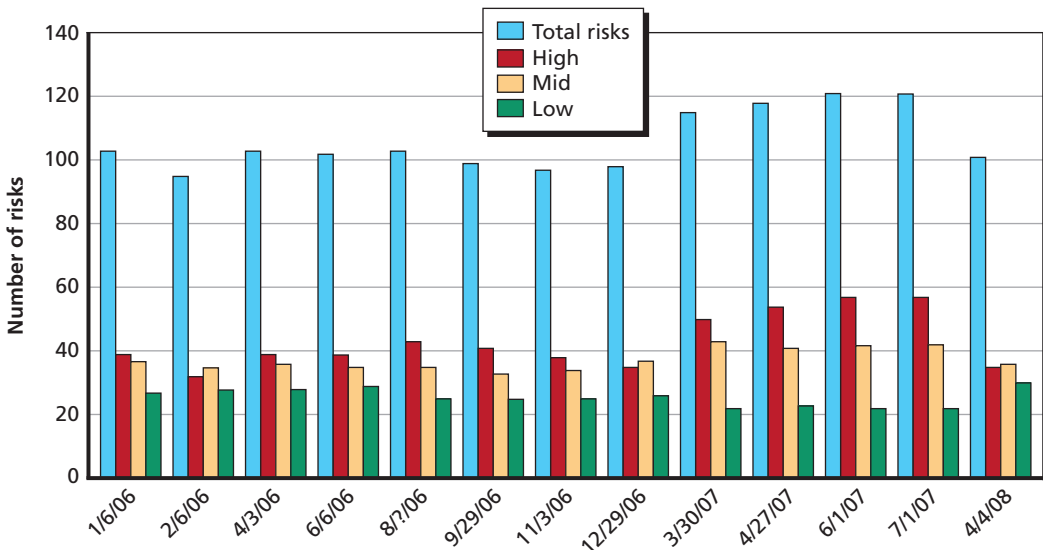
egorized as IPT- or program-level risk. Most risk management methods, when actually executed, focus only on risks that affect schedule or cost,¹⁵² but the FCS risk process looked more broadly, as verified by the December 2009 ARM entries.

Each CTE was tracked in the ARM database in terms of status and risk mitigation plan. Updates to at least the status of each CTE within ARM were event-driven, and occurred roughly every two to three months. The mitigation plans for some of the more novel and correspondingly immature technologies were based primarily on identification of the technology provider, such as an S&T program, rather than implementation details, as would be the case for mature technologies.

In addition to the risk data housed in the ARM application, an overall FCS risk metric (green, yellow, or red) was generated, which was then further detailed in various reports and briefings (Figure 8.7).

Traditional risk management methods and tools don't have the capability to address the complexities of resource allocation across multiple systems.¹⁵³ The ARM tool used in FCS categorized risk by IPT, and although the IPT organizations are not all system specific, many of the risk entries did focus on a specific systems or family of systems (i.e., MGV).

Figure 8.7
FCS Risk Profile Evolution



NOTE: The Risk Profile Evolution chart data originates from the probability-of-success (Ps) file's PM comment sections. The detailed risk ratings in the Ps files are only for high-risk elements, for which a likelihood and consequence rating is given. For mid/low risk elements, that level of detail does not exist.

RAND MG1206-8.7

¹⁵² Creel and Ellison, 2008.

¹⁵³ Creel and Ellison, 2008.

For example, in late 2006, the lack of an available heavy fuel engine (HFE) for the Class I UAV with the required SWaP was identified as a risk because the HFE was an “absolute requirement for the customer.”¹⁵⁴ The mitigation strategy consisted of three steps: build prototype, test, and monitor /leverage other programs.¹⁵⁵ The mitigation plan further stated that significant effort was spent to leverage other programs to uncover viable engine vendors, excluding the option to avoid or transfer risk, and leaving only acceptance or mitigation of the risk.¹⁵⁶ Although the mitigation strategy articulated (to build a prototype) is sensible given the lack of an existing HFE, it focuses on the risk to the Class I platform or system, rather than trades performed to the SoS for risk management and mitigation purposes. The absoluteness of the requirement for an HFE-based Class I UAV may also embody a stove-piped perspective rather than SoS view to create more flexible requirements, which may allow other types of engines for the Class I. That is, if properly embodying a SoS vision within the large FCS program, additional options to that HFE should have existed.

As another example of a single-system focus rather than SoS approach, consider the risk and mitigation plan for “security systems and algorithms for intrusion detection” for the FCS network (CTE3B1). A lack of a presently available COTS or GOTS solution for protecting against intrusion on the tactical MANET was formalized as a risk with high likelihood and consequence.¹⁵⁷ The mitigation plan thus identified the provider of a potential solution, in this case the DARPA DCAMANET (Defense Against Cyber Attacks in Mobile Ad Hoc Networks) program, and it consisted of supporting continued research on this effort.¹⁵⁸ A 2004 TTA between the LSI and CERDEC to provide a potential network intrusion solution from the tactical wireless network assurance STO may also have been considered.¹⁵⁹ Again, given the lack of an existing solution for a CTE, risk mitigation can only realistically consist of specifying potential providers of technologies at some point in the near future. Identification of such risks is important in its own right, but for immature technologies without existing implementation, some level of risk acceptance is implied despite the preference for mitigation rather than explicit acceptance of the risk. This particular example is not

¹⁵⁴ Charles Cartwright, “Execution – Program Risk Assessment,” Altess AIM FCS Probability of Success, briefing slides, September 20, 2006.

¹⁵⁵ Cartwright, “Execution – Program Risk Assessment,” 2006.

¹⁵⁶ Cartwright, “Execution – Program Risk Assessment,” 2006.

¹⁵⁷ Cartwright, “Execution – Program Risk Assessment,” 2006.

¹⁵⁸ Cartwright, “Execution – Program Risk Assessment,” 2006.

¹⁵⁹ Technology Transition Agreement Between Program Manager, Future Combat Systems (PM FCS) and Director, Communications Electronics Research and Development Engineering Center (CERDEC), Subject: Collaboration for the Transition of Technology from CERDEC to PM FCS for the Security Systems and Algorithms Critical Technology Area, signed by Dennis Muilenburg (Vice President, LSI), Stephen Lucas (PM Tactical Wireless Network Assurance STO), and BG Charles Cartwright (Deputy Commanding General for SoS Integration, RDEC), March 30, 2004. Not available to the general public.

platform specific and may not be amenable to SoS-level trades to provide further flexibility within the risk mitigation context.

Accounting for the interactions of systems is crucial as changes in risk mitigation for individual systems can affect the collective behavior of the SoS.¹⁶⁰ Although organizational practices such as regular communication within and across IPTs can alert managers to unexpected consequences, an analytical approach to supplement and perhaps predict interactions between platforms and CTEs would increase the efficacy of risk mitigation efforts. The format of such a new approach is nontrivial and would necessitate considerable new thinking to be resolved.

Despite the lack of best practices for risk mitigation in SoS acquisition, it was asserted that the FCS risk management process was more rigorous than the standard DoD approach,¹⁶¹ using best practices available and being executed at the lowest levels. This was driven largely by the high-risk acquisition strategy predicated on novel technologies and aggressive requirements. Nonetheless, like FCS, future risk mitigation should incorporate SoS engineering practices, particularly exploring risk trades between systems. Such trades are especially important when systems require novel technologies with unavailable implementations so that the full parameter space of technical mitigation options may be explored.

Risk management administrators are keenly aware that even with the best methodology and execution, there is a tendency for technology developers to understate or omit potential risk items for fear of exceeding any perceived threshold of total risk. Managers focusing on prevention of risk can develop a mindset of “playing not to lose,” leading to overall increased risk.¹⁶² There are no existing best practices to address all of these risk management problems in the SoS realm,¹⁶³ but potential methodologies may be drawn from the software engineering field, which suggests analyzing a system or component from its functional usage in an operational context as a way to identify success criteria and stresses that push it beyond operational limits. The acquisition community may benefit from further work that can translate software SoS risk management practices to the hardware context and provide practical improvements over traditional risk mitigation methodology. Any effective risk management approach for SoS, or for a system that participates in an existing SoS, should be scaled to the size and complexity of the SoS, incorporate dynamics and interactions, integrate across the full life cycle of the program from requirements to sustainment, and focus on success as well as failure.¹⁶⁴

¹⁶⁰Creel and Ellison, 2008.

¹⁶¹Tony Desmond, “Subject: Future Combat Systems October 2007 Probability of Success (Ps) Follow-up,” FCS Information Paper, October 15, 2007.

¹⁶²Creel and Ellison, 2008.

¹⁶³Creel and Ellison, 2008.

¹⁶⁴Creel and Ellison, 2008.

M&S and Analysis Needed to Consolidate Disparate M&S Activities Beyond Organizational Structuring

Modeling and simulation (M&S) is a generic term implying the use of a simplified abstraction of a real situation or system whose features can then be analyzed by numerical simulation, mathematical analysis, or SME insight, as in the case of wargaming. Analysis is a similarly generic term that can use M&S to affect decisions on requirements generation and system design. However, there are two specific high-level categories of analysis employing M&S in FCS: mission-level and engineering-level, with the former concerned with operational issues employing the SoS and the latter supporting technical design activity for a system. The program's stated goals for both M&S and analysis were broad: optimize the force, define requirements, demonstrate performance, reduce risk, reach a balance of performance and cost (both in acquisition and life cycle), and lead to rapid manufacturing and responsive life cycle support.¹⁶⁵ Examples of analysis for force optimization and requirements definition exist as early as the CTD phase, when the various contractor teams tested their concepts for developing and optimizing the SoS force structure and for demonstrating the operational validity of technology choices using mission-level analysis conducted by TRADOC Analysis Center (TRAC).¹⁶⁶ Risk mitigation plans also articulate the use of M&S such as for network reliability or APS development.¹⁶⁷ However, the 2009 cancellation of the program did not allow for life-cycle support application of M&S, and demonstrations were limited to specific system functionality rather than SoS functionality in an operationally relevant context.

Engineering-Level Analysis Needed to Link to Mission-Level Analysis for an Extended Amount of Time

The community of analysts involved at the mission level and engineering level use different M&S tools requiring different training and skill sets, but more importantly processes with different timescales that can inhibit the use of one to support the other. Mission-level analysis uses a variety of force-on-force simulators such as JANUS and CASTFOREM, which can be used to test CONOPS, to understand the possible effects of requirements, and in principle to support design decisions for individual systems. Engineering-level analysis requires technical details that are specific to systems and technology domains and thus employs a larger variety of M&S tools with greater usage frequency and less formality during system development. In a SoS with greater intentional and unintentional interactions between systems, there is a greater need for

¹⁶⁵ "Future Combat Systems Equipped Unit of Action Life Cycle Simulation Support Plan," Appendix H, Simulation Support Plan, Draft version 0.8, May 28, 2002. Not available to the general public.

¹⁶⁶ Interview data.

¹⁶⁷ "Future Combat Systems (FCS) Increment I Technology Readiness Assessment (TRA) Update," October 2004.

engagement between engineering-level and mission-level analysis to support system design activities and ensure that resulting designs are operationally relevant.

However, the Army's AR 5-11 directive requires a verification and validation (V&V) cycle¹⁶⁸ of mission-level M&S that can last many weeks and months. Such an extended period is not conducive to system design or to engineering-level analysis,¹⁶⁹ although results from a variety of FCS analysis efforts were mostly consistent, which may be attributed to such a robust process.

Additional Exploratory Concept Modeling and Technology Sensitivity Was Desired

The FCS program was built upon concepts of how a future force would operate, in addition to the various expectations for advanced and at-the-time unknown technologies. The short leadup to Milestone B limited the amount of concept exploration possible, and interviews with senior officials highlighted the desire for that capability.

A more flexible and rapid mission-level analysis process involving human-in-the-loop creativity along with M&S may enable discovery of new CONOPS or TTP, which after all is the motivation for creating SoS with novel capabilities like FCS. Yet SoS analytic techniques are still in their infancy¹⁷⁰ and will require further development to produce new CONOPS or dynamically employ different CONOPS in the course of a simulation. FCS mission-level analysis also had to contend with technology risks, namely the possibility that some of the CTEs might not be available. The Army should seek means to parametrically analyze this technological uncertainty within mission-level analysis, which would result in a method to operationally quantify such technological risks.

Coordination Within the Analytic Community Made Progress

The FCS analytic community was aware of the importance of a robust and interconnected M&S capability, linking technical knowledge through to operational effectiveness. Early in the program, the Army Materiel Systems Analysis Activity (AMSAA), the organization tasked with technical certification of model inputs within the Army, created a "Systems Book" to help coordinate model inputs with TRAC. The Systems Book described the platform characteristics, which analysts could then use in their efforts. Early characteristics were largely derived from requirements and early specifications of the systems. As the program evolved, and as additional information about the technologies and capabilities (and limitations) was known, the Systems Book began to describe the status of those technologies. The technical status as embodied by the then-current design parameters was, at times, in conflict with the requirements, and

¹⁶⁸Department of the Army, "Verification, Validation, and Accreditation of Army Models and Simulation," Army Pamphlet 5-11, 1999.

¹⁶⁹Interview data.

¹⁷⁰Interview data.

thus the existence of this Systems Book caused some concern across the program as to its goal. That is, as the technologies were being developed, the ability to meet the overarching requirements became less obvious.

To some, the Systems Book was seen both as an M&S coordination mechanism and as a summary of technical progress in meeting requirements. The last official version of the Systems Book was signed in 2003, although additional versions were later created but not officially certified by AMSAA.¹⁷¹ Discussions with program officials highlighted the reasons—that the systems described in the Systems Book were too far afield from the “official” requirements of the program and thus sending an undesirable message about the health and progress of the program. Additionally, at the time, it was unclear what responsibility and role an Army technical center such as AMSAA should be playing in validating technical progress of a central Army effort. The need to understand the technical underpinnings of the requirements is a theme throughout this report, and something the Army needs to incorporate better into future programs.

Nonetheless, at an organizational level, in order to better coordinate and synchronize the variety of analytical efforts ongoing in the program, the FCS Analysis Integration Group (AIG) was created. The AIG consisted of the Army Capabilities Integration Center (ARCIC), the PM FCS, and the LSI, among others.¹⁷² It directed and integrated analysis of issues that arose from several organizations (HQDA/OSD, EBCT, PM FCS, ARCIC/FFID, ATEC, AMSAA) using the FCS Integrated Analysis Plan developed by ARCIC.

An example of this analysis coordination process arose in September 2005, when a TRADOC memorandum tasked Army Combined Arms Support Command (CASCOM) and TRAC to develop a list of common logistics assumptions to be used in future analysis. TRAC (Fort Lee) immediately began work under the guidance of AIG, producing the first versions of a white paper in July 2006.¹⁷³ Anecdotal evidence suggests there was sufficient M&S support for decision makers, although it was often untimely and tended to lag decisions.¹⁷⁴ The Army believes that FCS AIG was beneficial in this M&S integration role, but was not able to synchronize LSI and government efforts to support key program decision points, such as LSI vehicle design itera-

¹⁷¹Additional collections of baseline data existed within the program, such as the “Design Concept Baseline” (DCB). By 2004 and 2005, the DCB and Systems Book were diverging in content, and while AMSAA officially signed off on some versions of the DCB, on others it did not, according to senior officials.

¹⁷²“Network Analysis and Modeling for FCS,” PM FCS (BCT) M&S Office, C3 Hierarchies Workshop, December 4, 2007. Not available to the general public.

¹⁷³“Future Combat System Logistics Assumptions White Paper,” Integrated Logistics Analysis Plan Working Group, September 5, 2008. Not available to the general public.

¹⁷⁴Interview data.

tions and government assessments of survivability and network.¹⁷⁵ The AIG, and other manifestations of coordination among analytic groups supporting major acquisition programs, was broadly seen as a good idea for future programs and necessary for consideration in future acquisition programs.

In order to ensure consistency and concurrency of M&S across the various organizations involved in each of these activities, a Cross-Command Collaboration Effort (3CE) system was developed.¹⁷⁶ 3CE is a computer network of 52 M&S facilities across four commands: TRADOC (Battle Labs and Analysis Centers), ATEC (Test Centers), RDECOM, and the LSI System of Systems Integration Labs. With 3CE in place, the four organizations agreed to use a common set of M&S tools for FCS, with OneSAF being the primary force-on-force simulator, and the Communications Effects Server (CES) as the primary communications M&S tool.¹⁷⁷ In providing a capability to conduct distributed experimentation, testing, and analysis through M&S, it sought to support the larger overall goal of life cycle program decision making by PM FCS. In addition to providing a network that enabled sharing of data and M&S capabilities across the requirements, testing, and design commands, 3CE aimed to share organizational best practices and enhance collaboration that would also be useful for future acquisition programs. TARDEC, ARCIC, and the Maneuver Center of Excellence are currently developing an initiative to enable an earlier link of development and requirements for the GCV program, and are starting to use 3CE for this purpose.¹⁷⁸ At present the 3CE effort has transitioned to AAMSES.¹⁷⁹

The importance of analysis and M&S in FCS extends even further as the stated central tenet of the acquisition approach, called Simulation Based Acquisition (SBA). FCS would be the Army's flagship SBA program.¹⁸⁰ The SBA approach would be executed in accordance with the Army framework entitled Simulation and Modeling for Acquisition, Requirements, and Training (SMART) and implemented by the FCS

¹⁷⁵U.S. Army, "FCS After Action Review," June 3, 2009 v.16, Fort Myers Officer Club. Not available to the general public.

¹⁷⁶"Cross-Command Collaboration Effort (3CE)," October 3, 2008, Approved for Public Release—Case GOVT 08-8101.

¹⁷⁷Interview data.

¹⁷⁸Interview data.

¹⁷⁹See "Exhibit R-2, RDT&E Budget Item Justification: PB 2011 Army," February 2010, pp. 870–872:

Transitions from funding of the Cross Command Collaboration Effort (3CE) to establish the Army Acquisition M&S Enterprise Solution (AAMSES) to support the new Army Modernization strategy. AAMSES will provide the required capability to transition overarching M&S development and integration responsibility from the contractor to the Government, and provide for a sustainable simulation environment to allow soldiers to execute and evaluate modernization capabilities in an operationally relevant and realistic synthetic environment.

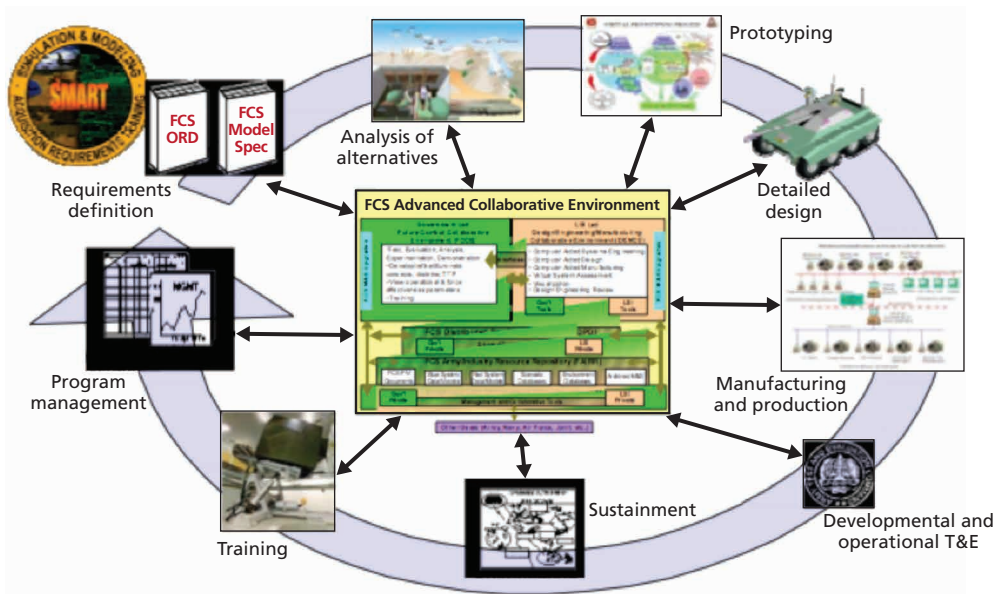
¹⁸⁰"Future Combat Systems Equipped Unit of Action Life Cycle Simulation Support Plan," 2002.

M&S Management Office.¹⁸¹ (See Figure 8.8.) The three key concepts of SMART are: continuous collaboration of system stakeholders throughout the product life cycle, system development execution through a document management application called the Advanced Collaboration Environment (ACE), and a single source of verified product information to ensure a consistent representation of FCS in all M&S activities.

FCS Had a Robust Testing Plan

Testing is a standard engineering practice in technology development and occurs at various stages from prototyping to full product development. Experience within DoD and commercial endeavors has shown the importance of developing a test strategy early in a product development cycle to ensure that requisite functionality can be tested, either in a laboratory or with field tests, once a prototype or final product is assembled. As stated in the *Defense Acquisition Guidebook*, all MDAP are required to submit a test and evaluation master plan (TEMP) for OSD approval for Milestone B.¹⁸² The guidebook also states that special care must be taken for SoS testing but only since August 2008 has USD(AT&L) produced a systems engineering guide for SoS, which describes

Figure 8.8
Using M&S Throughout the Life Cycle Achieves SMART Goals



¹⁸¹ PM FCS BCT, "Acquisition Strategy Report, Revision 2, Future Combat Systems," Sec. 4.6.3, 2008.

¹⁸² *Defense Acquisition Guidebook*, Chapter 9, "Test and Evaluation."

these challenges and emphasizes the importance and advantages of validation through M&S.¹⁸³

The first TEMP produced by PM FCS in April 2003 was approved by OSD in May 2003, but required an update with additional details on contractor developmental test plans prior to the FY04 OSD PDR review.¹⁸⁴ The July 2004 restructuring of FCS, however, delayed the OSD review of an updated TEMP,¹⁸⁵ with the DoD approving the FCS TEMP in 2006 but eventually requiring a complete TEMP update in August 2008 to reflect the program restructure of January 2007.¹⁸⁶ The 2006 update to the TEMP specified additional operational testing to address individual system performance.¹⁸⁷

Because of their greater complexity, systems of systems have unique design challenges compared to a single system. Any evaluation strategy will be correspondingly difficult to craft, a sentiment echoed by the TEMP:¹⁸⁸

The FCS TEMP is unique, not only because of its magnitude and scope, but also because it has to address the capabilities of the individual FCS systems and the FCS FoS, as well as the contributions of the FCS and their complementary systems to UA mission performance.

An additional feature unique to FCS relative to a majority of Army acquisitions was the simultaneous creation of a new brigade structure, along with the platforms and technologies, requiring simultaneous brigade training and new equipment training.¹⁸⁹ The program also recognized the need to reduce duplicative testing performed by the government and system contractors by planning for a single contractor-lead integrated qualification testing period,¹⁹⁰ which would provide data for specification compliance and government evaluation to support an initial production decision. The evolution

¹⁸³ Office of the Deputy Under Secretary of Defense for Acquisition and Technology, Systems and Software Engineering, *Systems Engineering Guide for Systems of Systems*, Version 1.0, Washington, D.C.: ODUSD(A&T) SSE, 2008.

¹⁸⁴ Thomas Christie (Director Operational Test and Evaluation) and Glenn Lamartin (Director Defense Systems OUSD(AT&L)), memorandum for DUSD Army, Subject: Test and Evaluation Master Plan (TEMP) for the Future Combat System (FCS) Test and Evaluation Master Plan Rev. 14, April 2003.

¹⁸⁵ Office of the Secretary of Defense, *Future Combat System (FCS) Munitions*, no date.

¹⁸⁶ Finley, "Testimony before the U.S. House Committee on Armed Services Air and Land Forces Subcommittee," March 27, 2007.

¹⁸⁷ Office of the Secretary of Defense, *Future Combat Systems (FCS) Overview*, 2006.

¹⁸⁸ FCS TEMP, April 2003.

¹⁸⁹ FCS TEMP, April 2003.

¹⁹⁰ An IDA study concluded that brigade-level integration, validation, and testing was inadequately funded. "Future Combat Systems (FCS) SDD Cost Review Findings," Alexandria, Va.: Institute for Defense Analyses, January 2009.

of user and operational testing would occur with multiple limited user tests (LUTs), each with increasing number and maturity of hardware systems in greater complexity operational environments and scenarios. The third LUT, along with a proposed Army operational evaluation/certification exercise (OE/CE), would serve as the IOC. The FCS program was cancelled with less than half of testing having been accomplished, but the plan and intent can still be considered.

Advanced Testing Capabilities Were Built for FCS

In any complex system, it is important to test interactions between hardware and software subsystems, even if they are not part of the design intent. For example, Carnegie Mellon University's Robotics Institute has developed a UGV Systems Integration Lab (SIL) to test electromechanical and computerized subsystems together prior to fielding, while allowing engineers to evaluate subsystems individually or in combination to observe interactions.¹⁹¹

The FCS program used an incremental integration and verification (I&V) process, which began with components and progressed toward the SoS as the various components become available for I&V. The program developed a network of SILs¹⁹² and an overarching Systems of Systems Integration Lab (SoSIL)¹⁹³ to immerse the platforms in a realistic yet virtual battlefield for end-to-end real-time brigade-sized testing.¹⁹⁴ In fact the SoSIL would be required to meet the SDD exit criterion relating to maintainability and sustainability. Five platforms representing MGV, UGV, UAV, UGS, and NLOS-LS would need to demonstrate their diagnostics effectiveness by achieving a 95 percent fault identification and isolation rate. These faults would be inserted through SoSIL testing capabilities. In the testing context, the SoSIL was anticipated to provide a simulation and emulation environment after the initial system-level testing phase and continuing with greater fidelity as platform development progressed. A distributed testing capability is an important component to SoS testing, especially for network-centric warfare.¹⁹⁵ The program was cancelled before the SoSIL could be used for its intended role in meeting the SDD exit criteria.

The FCS TEMP also emphasized the need for integrating technical and operational testing, assuming a unit would be committed to FCS development and would eventually become the Army's first UA. This unit would conduct operational testing at

¹⁹¹National Robotics Engineering Center, Carnegie Mellon University, UGV Systems Integration Lab, 2011.

¹⁹²A total of six SILs were projected: three MGV SILs, one UGV SIL, one UAV SIL, and one Training SIL. See briefing, "FCS Test and Evaluation Infrastructure Concept," July 11, 2003. Not available to the general public.

¹⁹³Eric Cramer, *Army News Service*, January 26, 2005.

¹⁹⁴PM FCS BCT, "Acquisition Strategy Report, Revision 2, Future Combat Systems," 2008.

¹⁹⁵Stephen F. Conley, "Test and Evaluation Strategies for Network-Enabled Systems," *ITEA Journal*, Vol. 30, 2009, pp. 111–116.

various test events, including user test scenarios for integration testing in the SoSILs, initial qualification test, initial verification test, and initial operation test.

In 2005 the Future Force Integration Directorate (FFID) was created to facilitate training, testing and evaluation of FCS with authority over the Army Evaluation Task Force (AETF), a unit of soldiers that would test and evaluate FCS test equipment.¹⁹⁶

The spiral strategy resulting from the 2005 restructuring, and the importance of the network technologies, prompted the GAO to recommend an operational test and evaluation strategy to support an evaluation of network maturity as part of FCS spiral production decisions.¹⁹⁷ The DoD concurred with this recommendation, saying it would field existing and new communication equipment in addition to stressing iterative operational test and evaluation. Two years earlier, however, a published version of the TEMP¹⁹⁸ had already recognized the importance of continuous network testing through all phases of the test program as well as at multiple levels within each phase to provide an evaluation of the network maturity at each test event.¹⁹⁹

FCS Participation in Joint Exercises Provided Value

The continuous testing of the network during each of the test phases would give an indication of the maturation of network capabilities. This type of network testing was exemplified in the joint JEFX 08 exercise, where valuable lessons were also learned.²⁰⁰

FCS participation in JEFX 08 successfully met and exceeded all planned “Live Fly” test objectives and completed the program assessment objectives (risk elements) for the Experiment 2.1 (Spiral 2, Spiral 3, and MainEx). A total of 77 assessment objectives were completed during JEFX 08 that focused on

- Army Aviation (attack helicopter/Apache, CLIV UAV surrogate, and CLI UAV),
- network communication (Ground Mobile Radios, SLICE, TTNT, and High-band Networking Waveform (HNW), Non-Organic Systems),

¹⁹⁶Brigade Modernization Command, *BMC History*.

¹⁹⁷Government Accountability Office, *Defense Acquisitions: Resolving Development Risks in the Army's Networked Communications Capabilities Is Key to Fielding Future Force*, Washington, D.C.: Government Accountability Office, GAO-05-669, June 2005.

¹⁹⁸Christie and Lamartin, April 2003.

¹⁹⁹Furthermore, the National Defense Authorization Act of 2008 required

(a) an evaluation of the FCS network's capability to transmit the volume and classes of data required by Future Combat Systems approved requirements; and (b) an evaluation of the FCS network performance in a degraded condition due to enemy network attack, sophisticated enemy electronic warfare, adverse weather conditions, and terrain variability.

²⁰⁰ For example, participation in JEFX 08 highlighted the need to focus on network security provided by the cross-domain guarding CTE. Since all elements touched the SIPRNet, FCS concentrated on site-specific security for classified testing at Boeing as well as the Department of Defense Information Assurance Certification and Accreditation Process (DIACAP) to obtain an Interim Authority to Operate (IATO) for field testing. The cross-domain guard was equally challenging, as was TEMPEST, COMSEC, and export authorization.

- Soldiers,
- Joint Services (USMC/Navy),
- Coalition force (UK), and
- situational awareness (SA) exchange on the global information grid (GIG).²⁰¹

The importance of joint DoD-wide exercises for network testing also serves to progress the ultimate goal for all services to be GIG compliant and operate seamlessly in a one-net-centric information exchange environment.²⁰²

SoS Testing for Network Functionality Was Challenged by Determining What Level of Network Functionality Was Required

A challenge for testing a network-centric SoS is to determine how to accurately test the functionality of the SoS when network development is proceeding in parallel with system development and may not have converged to the final architecture or communication protocols. A sentiment echoed during interviews, namely that “not everything has to be tested in a network environment,” expresses the challenge of determining exactly what level of network functionality is required for accurate SoS functional testing that will further system and network development. For example, in testing the UGS, which captures and relays image data to other systems and dismounted soldiers in the SoS, a relatively high level of network functionality would be expected to test the utility of this system. In contrast, functional testing of the APS, which serves to protect a single MGV, may require a relatively lower level of network functionality. Yet one can imagine that dismounted soldiers or other nearby systems may need to be forewarned prior to the APS countermeasure being initiated to avoid collateral damage, and such a warning protocol would require some network functionality. In reality, network development and system development will proceed at different rates and subsystem testing will occur with limited network functionality.

Testing Incrementally Improved M&S

The fusion of M&S and testing was necessary to the acquisition and development of FCS, as stated in the simulation support plan (SSP): “Integrated simulation and test generates significantly more understanding of the FCS and environment interaction than either M&S or testing alone.”²⁰³ The SSP states that the program will use the DoD simulation test and evaluation process (STEP), which uses M&S to predict system performance that then informs testing, which generates empirical data that can

²⁰¹“FCS Network Experimentation Experiment 2.1/Joint Expeditionary Force Experiment 2008.” Not available to the general public.

²⁰²Conley, 2009.

²⁰³“Future Combat Systems Equipped Unit of Action Life Cycle Simulation Support Plan,” 2002.

be used to validate and refine M&S tools, a feedback cycle embodying fundamentally sound engineering practices.

Some history from the testing of the Active Protection System exemplifies the philosophy of STEP. The APS, consisting of the Short Range and Long Range Countermeasures (SRCM and LRCM), and the Multi-Function Radio-Frequency System (a tracking radar) are just two of many components of the Hit Avoidance Suite which were expected to be on MGV and play an important role in its survivability. In 2008, an SRCM design verification test was conducted to verify that the Eject Gas Generator and Pitch over Motor components functioned properly to defeat an RPG statically and on-the-move.²⁰⁴ The results of this testing were forwarded to AMSAA and ARL for input to the SRCM M&S. The test data would then presumably be used to validate and improve the model for SRCM, and thus the overall model for APS, as alluded to in STEP. In principle, the improvement gained in the subsystem M&S would improve engineering-level analysis of this subsystem and thereby its parent system. If these M&S improvements were further incorporated in the hierarchy of models that represent the system and SoS, this could improve the fidelity of mission-level analysis. Yet this incremental improvement in the M&S hierarchy of the SoS through testing various subsystems presumes that this knowledge of models and their refinement is readily available throughout the technical community in the program. Our interviews have indicated a lack of such awareness and the need to consolidate the disparate M&S activities beyond just organizational structuring.

Conclusions and Lessons

Conclusions

The FCS program was ambitious in its expectations for technology development. When the LSI was chosen in March 2002, it was a scant 14 months to Milestone B in May 2003. Technology development, therefore, largely took place in SDD. In 2003, only a small fraction of the critical technologies had reached technical maturity typically associated with that milestone. By 2009, many more had reached that threshold, though others were still far from meeting the overall goals of the FCS program. Those technologies had developed during the SDD phase concomitant with requirements changes and concept updates, which increased the complexity and risk in the program and eventually contributed to the cancellation.

The FCS program was predicated on significant leaps in technology. In this chapter we covered only a few specific examples among many—the specific batteries on the manned-ground vehicles, portions of the hit avoidance system, and the ubiquitous and

²⁰⁴Brian Sauser et al., “A Systems Approach to Expanding the Technology Readiness Level within Defense Acquisition,” *International Journal of Defense Acquisition Management*, Vol. 1, 2008, pp. 39–58.

revolutionary network. Each showed sophisticated thinking on how those technologies might revolutionize the way the Army fought, but suffered from lack of fundamental knowledge of their technical merit. Technologies once thought to be developing were shown to not be. And the technical personnel to track, understand, and solve emerging problems were in need in a variety of disciplines and at unexpected levels—something the Army will have to still address as many of the technologies in FCS are simply not going away.

The significant challenges in technologies, however, spurred innovative methods in many spheres. From the system and SoS integration labs to the evaluation brigades, the FCS program made strides in how to conceptualize, test, and appreciate the value of brigade-set fielding and the utility of modeling and simulation in support of it. Additionally, knowledge about networking within the Army, as well as the inherent limitations that exist in the vision of a net-centric Army, was being built through the FCS program. By the end of FCS, some of the limitations of the technologies were just becoming apparent. The network, for one, was shown to have significant limitations—something that will affect the expected value that net-centric operations might bring to many ongoing Army programs.

Lessons

We offer here a number of lessons for the Army to consider.

Significant technology development should not occur late in acquisition programs. The Army will always need to push the bounds of technology to keep ahead of the threat and meet the needs of the nation. However, that technical development must be rooted in exploratory basic science and advanced development programs validated by early and realistic field experimentation with real products, and not in SDD phases of major acquisition programs.

Documentation of the state of the art for each critical technology element will identify risk and areas for increased investment. Future programs should analyze and document, perhaps as part of the TRA or TMA, the state of the art for each CTE, using sensible metrics found in scientific literature. Not only is this a common practice in technology development, it would also readily justify the need to invest in developing each critical technology, which by definition is novel itself or in its application, rather than using existing implementations. Furthermore, a quantifiable metric relevant to each CTE will clearly convey the ambitiousness of what is achievable at present and what is required for SoS functionality. In addition, the TRA should also specify the source of each CTE, whether an S&T ATO, CP, GOTS, or COTS solution and how it represents the state of the art in terms of this quantifiable technical metric. The 2003 Milestone B and 2004 Milestone B update TRAs refer to potential sources (ATO, CP, etc.) to realize a CTE, but these are not elaborated with technical metrics to justify them as the best choice for the requisite capabilities, or how ambitious the technology goals actually are. Resources required to successfully develop each CTE

can then be appropriately allocated or requested commensurate with the difficulty of extending the state of the art. In cases, where a technology is a CTE because it is being applied differently, it may not appear as leaping ahead of the state of the art, and in this case a qualitative discussion of its ambitiousness may be more appropriate, while providing the ASA(ALT) a high-level understanding of the novelty and necessity for SoS functionality.

Alternative technology assessment metrics can supplement TRLs, which may be inadequate for some aspect of SoS acquisitions. Although TRLs are accepted as a valuable metric for determining the maturity of individual CTEs, they may not be appropriate for addressing system integration or the system as a whole, due the following constraints: (1) the inability to represent integration between technologies, (2) an uncertainty in the actual maturation times of technologies, and (3) an inability to compare the impact of alternative TRLs on the system as a whole.²⁰⁵

In addition to the TRL, there are other metrics relevant to key characteristics of FCS systems that need further development. One example is integration readiness levels, which the ASA(ALT)'s IRT recommended using in design reviews as early as 2003,²⁰⁶ although it does not seem they were applied in later TMAs. Integration readiness levels have been shown to highlight low levels of integration maturity, whereas a specific mathematical combination of TRL and IRL has been advocated to produce a system-wide metric of readiness called the SRL.²⁰⁷ Others have also suggested that TRLs, MRLs, and SRLs aid developers in identifying the areas of risk, so that necessary strategic plans can be formulated to ensure timely development.²⁰⁸ One limit of the SRL approach is the inability to compare markedly different systems with SRLs.²⁰⁹ The GAO also recommends the use of manufacturing readiness levels throughout the various phases of a program. TRLs, MRLs, and SRLs are critical to objectively measuring the maturity of a technology. These metrics, as well as CTEs, help determine the extent to which the technology is appropriate for the solution and guide the development of downstream user evaluation criteria.²¹⁰

Another metric that may require improved methodology to assess in practice is commonality amongst systems, which in the case of FCS meant 80 percent commonality amongst MGCV variants. Although vehicle designers used a common chassis for the MGCV that could be modified to fit mission packages required for the different vari-

²⁰⁵Sauser et al., 2008, pp. 39–58.

²⁰⁶Dr. Larry Delaney, "Independent Review of Technology Maturity Assessments for FCS Increment 1," March 3, 2003; Delaney, 2008.

²⁰⁷Donnie Tew and Kevin Wallace, *An Analysis of Technology Transition Within the Department of Defense*, Naval Postgraduate School June 2010.

²⁰⁸Tew and Wallace, 2010.

²⁰⁹Tew and Wallace, 2010.

²¹⁰Tew and Wallace, 2010.

ants, they struggled²¹¹ with how to measure commonality in their designs. Programs should look to future research in the systems engineering community for guidance on how to use the various metrics in a coherent manner²¹² from both a SoS analysis and system design perspective, keeping close watch of unintended consequences that might accrue from over-constraining complex systems.

Including leading technical practitioners on IRTs can help determine technology maturity and improve accuracy of IRT assessments. The wide range of scientific and engineering disciplines required to assess the maturity of all 44 CTEs meant that the IRT relied on SMEs to form its conclusions. The IRT is the primary tool for the ASA(ALT) to provide an accurate and objective determination of technology maturity. It will be important to consider expanding the membership to technical practitioners drawn from engineering disciplines underlying the CTEs, who have hands-on experience in industry or in advanced research centers. In addition to improving the efficacy and efficiency of IRT assessments, an IRT augmented with practitioners, dedicated to the IRT process and timeline rather than as informal SMEs, can better negotiate technical criteria with the PM for each CTE to ensure a common understanding of specific benchmarks for TRL ratings, prior to the assessment cycle. Timely agreement of assessment criteria can increase the utility of the IRT review cycle.

Using SoS requirements to identify complementary programs can help schedule synchronization issues. Formally recognizing program interdependencies is an acquisitions requirement,²¹³ but an overly expansive list of CPs can generate a perception of greater complexity than can be afforded by the program's timeline or resources. This identification of CPs should be based on technical requirements and the SoS specifications.²¹⁴ As part of the technology development strategy, each CP should be linked to either producing a CTE or providing a system function—noting that many CPs are legacy capabilities, which will need to interoperate with the new system. Analysis of how the SoS concept will rely on the specific technology solutions provided by the CPs requires input from the requirements, analysis, and systems engineering communities and should be performed prior to the Milestone B review. In addition, prior to CP inclusion in a program baseline, upfront analysis is needed to determine how schedules will be synched.

The history of synchronization across multiple programs is thin, with notable examples of replanned product improvement efforts, which typically are limited in scope as well as duration. At cancellation, the FCS program had not reached the point of defining exactly how new increments of technology would be spiraled into FCS-equipped brigades.

²¹¹ Interview data.

²¹² How to use MRL, IRL, and SRL together is left as a future research question in Sauser et al., 2008.

²¹³ *Defense Acquisition Guidebook*, Section 2.2.5.

²¹⁴ Interview data.

Having too many connections to or being too highly dependent on outside programs can lead to significant risk. The FCS program was expected to interoperate with many legacy or developmental radio systems, with JTRS and WIN-T being the most well known. However, FCS struggled for the first two to three years to understand the status of JTRS.²¹⁵ Furthermore, the ORD specified JTRS as the primary radio for FCS, discouraging analysis of alternative radios that, although less capable, may have provided some fraction of desired operational capabilities. As a result, FCS was wholly dependent on the JTRS, a CTE, to create the network that would enable the SoS to provide the requisite situational awareness for lethality and survivability. Future acquisitions must ensure that any CTE provided by a CP must have an internally funded program alternative to hedge the possibility that design changes or schedule synchronization may not be influenced by program management constructs. Even a cursory cost analysis of such an internally funded alternative will reveal if such a hedging option is viable within the program's budget and, if not, at least motivate a thorough technical compatibility analysis from the SoS perspective before assuming complete dependence on the CP.

Risk mitigation strategies that incorporate SoS engineering practices can facilitate risk mitigation across systems. Despite the lack of best practices for risk mitigation in SoS acquisition, it was asserted that the FCS risk management process was more rigorous than the standard DoD approach,²¹⁶ using best practices available and being executed at the lowest levels. Nonetheless, it is our recommendation that risk mitigation should incorporate SoS engineering practices, particularly that of exploring risk trades between systems. Such trades are especially important when systems require novel technologies with unavailable implementations so that the full parameter space of technical mitigation options may be explored.

There are no existing best practices to address all of these risk management problems in the SoS realm.²¹⁷ However, potential methodologies may be drawn from the software engineering field, which suggests analyzing a system or component from its functional usage in an operational context as a way to identify success criteria and stresses that push it beyond operational limits. The acquisition community may benefit from further work that can translate software SoS risk management practices to the hardware context and provide practical improvements over traditional risk mitigation methodology. Any effective risk management approach for SoS, or for a system that participates in an existing SoS, should: scale to the size and complexity of the SoS, incorporate dynamics and interactions, integrate across the full life cycle of the program from requirements to sustainment, and focus on success as well as failure.²¹⁸

²¹⁵ Interview data.

²¹⁶ Desmond, "Subject: Future Combat Systems October 2007 Probability of Success (Ps) Follow-up," 2007.

²¹⁷ Desmond, "Subject: Future Combat Systems October 2007 Probability of Success (Ps) Follow-up," 2007.

²¹⁸ Desmond, "Subject: Future Combat Systems October 2007 Probability of Success (Ps) Follow-up," 2007.

A shared modeling and simulation repository can improve the fidelity of mission-level analysis. Our interviews have indicated a lack of such awareness and the need to consolidate the disparate M&S activities beyond just organizational structuring. One way the Army was heading in the FCS program was through a model data and documentation repository as part of AAMSES (previously known as 3CE) that allowed different analysts to translate improvements in one level of the modeling hierarchy to the next and thereby improve the fidelity and utility of mission-level analysis. These improvements in mission-level analysis would allow a broader understanding of the type of CONOPS capabilities provided by the SoS and also support design decisions for individual systems.

Incorporating mission-based vignettes in developmental test adds robustness to vignettes planned for operational tests. Even in early system development, the parameters of any mission-based vignette may influence testing conditions that otherwise may be determined in an ad hoc fashion. To realize this paradigm of capabilities-based testing will require earlier coordination between network developers, mission-level analysts, relevant system developers, and the test community to ensure a consistent translation of vignette parameters to physical test conditions, with accurate network assumptions. Such an organizational change to influence the test strategy must occur well before the TEMP is formalized and submitted for DoD approval.

Influencing S&T priorities by the AAE will help ensure their relevance to current threats and future missions. However, they should do so with a greater emphasis on relevance to current threats in addition to future projected missions. The existing ATO policy,²¹⁹ which requires an ATO to establish a TTA at least twelve months before completion, could be extended to develop a “preliminary TTA” at the inception of an ATO to allow greater interaction between the S&T community and PMs in the acquisition community. Such an earlier agreement may allow S&T efforts more visibility of changing acquisition emphasis between near-term and further-term needs, while providing the acquisition community greater flexibility in tailoring incremental deliverables to ensure some output prior to any shifts in S&T resource allocation that may be required by ongoing operational demands. Generally, FCS program officials considered S&T easier to interface with than complementary programs, due to the flexibility provided by the technology objective mandates to transition into a program of record.²²⁰

²¹⁹Department of the Army, “Army Acquisition Procedures,” Technology maturity and transition, Pamphlet 70-3, Section 1–23, January 2008.

²²⁰Interview data.

Summary

The cancellation of the Army's largest-ever systems development and its most expensive program termination during the past 20 years sent a shock wave across the entire defense acquisition community and raised doubts about the ability of any service to carry out such a large and complex program. The FCS program has been the subject of a number of postmortems, many quite negative. This report provides a select history of the program, while highlighting both positive innovations and several reasons for its ultimate failure.

The report included four main areas of discussion. First, it described the leadup to the FCS program in the 1990s and the Army's view of what the future would look like and how it would fight. These laid the conditions for what the FCS program was eventually to provide. Second, the report discussed how the requirements were generated for the program, and how those requirements developed. Third, it discussed how the program was managed and executed, particularly the Army's relationships with the LSI. Last, the report described how the original technologies were chosen, how they developed, and where they ended up.

The Initial Conditions

The 1990s were a period of transition for the Army along multiple fronts. The Cold War was ending, and the Army had performed well in the Gulf War but had taken months to build up its forces. That and the experience in Kosovo caused some to raise questions about the relevance of a ponderously heavy force during a time when speed and agility in deployment appeared to assume greater import. Simultaneously, advances in networking, information collection, and technology sparked interest in revolutionary approaches to warfare that might change the entire approach to fighting wars.

As a result, the Army looked toward a concept of warfare that departed dramatically from conventional war that had dominated its thinking for decades. It now looked to field a force that could deploy rapidly—a brigade that could deploy anywhere in a few days and divisions not far behind. But speed meant lightness, and for light forces to survive, they needed superb knowledge of the enemy. This led to a reliance on

concepts that required technologies carrying considerable risk, further challenged by the rapidity of the planned acquisition.

The Ensuing Acquisition Program

The original FCS program began as a collaboration between the Army and DARPA. It developed a vision of a new type of brigade comprised of some 18 systems all linked together by a revolutionary network. The vision ultimately called for this new brigade to replace all current combat units.

The acquisition program this vision spawned was nothing short of revolutionary. It relied on cutting-edge technologies that were not well understood at program initiation and sought to bring them into the force through new management approaches that brought industry into close collaboration with the Army. The program was also predicated on understanding and capitalizing on complex interactions within Army units to create the capabilities envisioned. Finally, the program had to move rapidly to meet the ambitious timelines the Chief of Staff of the Army had set for it.

While the Army was embroiled in two major wars overseas, the program was restructured multiple times. Systems were removed from the program for budgetary or technological reasons, only to be reintroduced and then removed again years later. The changes created internal turbulence that diverted time and attention from carrying out an ambitious and challenging program. Costs climbed, largely because of Army decisions, and the schedule was forced farther and farther into the future. Problems in technology development emerged, and these were followed by compromises to the operational requirements. Decisionmakers outside the Army saw a program collapsing along multiple axes, while the Army believed and insisted the program was on track.

Generating and Updating Requirements for FCS

Requirements played a pivotal role in the FCS story. The Army's combat developers set out to design an entire brigade of networked systems and subsystems from the ground up, taking advantage of advanced technologies that were largely underdeveloped, untested, and unknown, but were assumed eventually to be capable of achieving revolutionary levels of interoperability and tactical coordination. They also strove to produce a brigade that could deploy almost anywhere in 96 hours. At the same time, the wars the Army was fighting challenged some of the conceptual underpinnings of the entire FCS concept. Information flowing back from combat operations in Iraq and Afghanistan was at odds with some of the keystone assumptions of FCS.

FCS requirements were often untenable. Several core requirements were unrealistic, a large number of overspecified system-level requirements undermined the system-

of-systems development approach, and some concepts and requirements failed to adjust to the realities of the operational environment in the current theaters. An absence of fall-back options deprived the program of flexibility essential to a program with high risk. However, the requirements did foment new ways of thinking about how the Army might fight, most notably fostering a system-of-systems view of units, which in turn fostered a system-of-systems approach to development.

One of the most significant flaws in the early FCS program was that it contained several untested but critical requirements for achieving the FCS operational concept, particularly with regard to transportability and near-perfect situational awareness through advanced network technologies. These requirements posed particularly high risks to the overall program, since the technologies were not validated and the program had no backup plan should they fail.

Managing the FCS Program

The scope and complexity of the FCS requirements suggested the need for equally ambitious and innovative processes and structures to manage its development. An incremental acquisition strategy was employed to field the FCS system of systems. As high-payoff technologies matured, they were to be integrated into the first FCS brigades, while longer-developed technologies would be included in later increments. To meet the ambitious program schedule, FCS research, development, systems engineering, testing, prototyping, and other key activities were conducted concurrently.

The Army was concerned about its ability to manage the complex integration tasks inherent in an acquisition program as ambitious as the FCS and, therefore, decided to hire a lead system integrator rather than a prime or multiple prime contractors. This led to a much closer “One Team” partnership than was typical for Army acquisition programs. The Army also employed Integrated Product Teams (IPTs), co-led by government and industry personnel, for the development and integration of all the FCS systems.

The Army’s decision to fast track the FCS program had serious implications for FCS program management. The concurrent development of multiple FCS systems was ultimately too complex for the Army and the LSI to manage, particularly given the frequent budget and program restructurings. The Army leadership and FCS program managers also introduced significant programmatic risk when they decided that key FCS capabilities would be brought to the SoS from complementary systems that were being developed outside the control of FCS program managers.

As the program underwent major changes, the execution of key management processes was challenged in scope and speed, and undermined by major changes in the program. At times it took many months to reprogram the Earned Value Management System (EVMS) in response to major changes. As a result, EVMS reporting on

cost and schedule ultimately did not reflect the program's mounting problems. Overall, the tools and processes for managing such a large and rapid program are simply not available at this time. The establishment of the Advanced Collaborative Environment (ACE) was a notable exception and may hold promise for future collaborative efforts in the Army.

Personnel are the most vital element of any acquisition effort, and the Army initially had access to its best acquisition talent for the FCS program. As the program progressed, though, the significant technical and programmatic challenges required additional government expertise, but this was hard to come by.

Technical Progress

At the time of the Milestone B decision, only a small fraction of the FCS technologies had reached the technical maturity typically associated with that milestone. Technology development, therefore, was largely displaced to SDD. Though many more technologies had adequately matured by 2009, others were still far from meeting the overall goals of the FCS program. Unfortunately, many of those technologies were the ones necessary to achieve the program's requirements, and too often there was not an alternative approach. The result was increased programmatic complexity and risk, which contributed to the restructuring and ultimate cancellation of the program in 2009.

The FCS program was predicated on significant leaps in technology. Concept developers were creative about how technologies might revolutionize warfighting, but they also suffered from a lack of fundamental technical knowledge. Technologies assumed to be developing were not, and coordination between the technologists and concept developers was inadequate.

But the challenges in technology development also led to significant innovation. From the system and SoS integration labs to the Evaluation Brigade, the FCS program developed methodologies and products to help conceptualize, test, and appreciate the value of brigade-set fielding. As well, the FCS program provided important knowledge about the science of networks and the limitations inherent in the current vision of a net-centric Army.

End Game

The FCS program failed to realize the Army's very ambitious vision. It also consumed research and development and acquisition funds that might have produced more concrete results had they been applied elsewhere. That said, the program did enjoy some important successes and blazed a path that can lead to important future capabilities.

Select Interviewees for This Study

This study was fortunate for having access to many individuals currently and previously involved with aspects of the FCS program. Our discussions with individuals were all accomplished without attribution to ensure free flow of ideas. Nonetheless, we include some participants who were amenable to being acknowledged as representatives of the types of experts interviewed.

Curt Adams	Scott Davis	Ingo May
Robert Backman	Tony Desmond	Bryan McVeigh
Michael Bauman	Alan Dinsmore	Paul Mehney
Tom Becker	Richard Ess	Mike Merlo
Gary Becquet	Cathy Fitch	Mary Miller
Pam Blechinger	Rod Gelhaus	Robin Pope
Clif Boyd	Ted Goetz	Jeff Purdy
Ed Brady	Bob Hannah	Al Resnick
Jim Bray	Mike Harrigan	Paul Rogers
Michael Brunskill	Bob Hobbs	Don Schenk
Dave Busse	John Hufstedler	Rickey Smith
Mike Byers	Henry Hughes	Keith Taggart
John Carlineo	Bob Killibrew	Jack Taylor
Marlin Carlsen	King Ko	Jerry Tyree
Ray Carnes	Bob LaPolice	Paul Wilson
Robert Chandler	Red Lawhern	Richard Wittstruck
Peter Cherry	Michael Lingenfelter	Joe Yakovac
Brad Cohen	Jonathan Maddux	Philomena Zimmerman
John Corsello	Susi Mann	

Congressional Decrements and Scrutiny

Congressional funding decrements to the FCS are having a cumulative impact on the program.

—December 2006 SAR

Introduction

A few years after Milestone B, the FCS program was under considerable scrutiny. In 2006, the program office pointed to congressional decrements to FCS funding as having significant impact on the program's future. The PM noted the following decrements: FY05 = \$268.2 million, FY06 = \$236 million, and FY07 = \$319.1 million, for a total decrement of \$823.3 million over the preceding three years.

FY04 and FY05

Before the FY05 decrement, FCS had already been subject to heightened oversight from Congress. The FY04 National Defense Authorization Act (NDAA) created constraints on the program in the form of required independent reports and demanded greater detail in the FCS budget justification materials submitted in support of the President's budget.¹ Regarding FY04 appropriation, the House Committee on Appropriations reported that it

Believes that the Army must substantially improve the justification for the various elements of this program to ensure that FCS will continue to compete successfully for resources. For example, the Committee is aware that 19 requests for proposals (RFPs) for various elements of the FCS were released in February, 2003. The Committee fully expects that each of these elements will present unique and distinguishable requirements for funding within this program. These requirements

¹ Public Law 108-136, National Defense Authorization Act for Fiscal Year 2004, November 24, 2003.

are simply not defined or supported by the budget request as presented for fiscal year 2004.²

The conference appropriations report that year echoes this same point, stating that “the Army must improve the structure of the budget estimates in support of the Future Combat System . . . Adding detail to the budget justification materials is essential to justify the requested level of funding.”³

The July 21, 2004 restructuring within the FCS program affected Congress’s view of the program. According to the Congressional Research Service, “[s]ome have maintained that this restructuring was intended to address the risks and other issues raised by external agencies such as GAO.”⁴ This change was announced by the Army exactly one day after the Conference Appropriations Committee issued its report for FY05. One of the changes implemented was to address language in the Conference Committee Report on the Non Line of Sight Cannon (NLOS-C).

Congress reiterated its desire for greater budget estimate detail in its reports preparing for FY05. The Ronald Reagan FY05 NDAA required the Secretary of the Army to establish and implement a detailed FCS “program strategy.”⁵ The NDAA further required that independent analysis on FCS’s costs and feasibility be submitted to Congress before the program’s Milestone B update. One of the required cost estimates was to be prepared by the Cost Analysis Improvement Group (CAIG) of the Office of the Secretary of Defense.⁶

A new concern arose in budgeting for FY05, in the form of the congressionally authorized end-strength boost to the Army by 20,000, establishing a new statutory Army permanent active duty minimum end-strength of 502,400.⁷ Some defense analysts noted at the time that the troop increase’s attendant costs put the FCS budget in jeopardy.⁸

The appropriations process for FY05 resulted in the \$268 million funding decrement noted in the December 2006 SAR. The House Appropriations Committee (HAC) noted “that the budget request includes both multiple layers of management reserve, as well as over \$100,000,000 for the purpose of program withholds and other

² H.R. Rep. No. 108-187, 2003.

³ H.R. Conf. Rep. No. 108-283, 2003.

⁴ Andrew Feickert, *The Army’s Future Combat Systems (FCS): Background and Issues for Congress*, Washington, D.C.: Congressional Research Service, RL32888, April 28, 2005.

⁵ Public Law 108-375, Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005, October 28, 2004.

⁶ Public Law 108-375, 2004.

⁷ Public Law 108-375, 2004.

⁸ Megan Scully, “Analysts: U.S. Soldier Boost Could Cut Materiel,” *Defense News*, June 28, 2004, p. 12.

‘taxes’ contrary to normal budget practices.”⁹ The HAC singled out the Non Line of Sight Launch System (NLOS-LS) for termination, citing redundant capabilities. The Senate Appropriations Committee (SAC) approved the FCS budget request in its entirety, specifically including full funding for the NLOS-LS.¹⁰ The Conference Committee resolved the discrepancy by providing \$58 million for NLOS-LS, instead of the requested \$76.4 million, while still eliminating the \$248 million in “overhead” identified in the HAC report.¹¹

FY06

Budgeting for FY06 followed a similar pattern to FY05, with congressional committees expressing skepticism regarding the administration’s submitted budget materials concerning FCS. In fact, the amount of skepticism toward FCS increased in budgeting for FY06, when measured by the number of committees initially recommending cuts in their reports. For FY05, both the House Armed Services Committee (HASC) and the HAC recommended cuts to the Army’s FCS budget, while the Senate Armed Services Committee (SASC) and SAC approved the Army’s submitted FCS budget without change. In budgeting for FY06, however, the SAC joined both House committees in recommending funding decrements for FCS. Although the SASC approved the full amount requested, it subjected to heightened scrutiny the decision to use “Other Transaction Authority” (OTA) to contract for FCS, as will be discussed below.

The continuing and arguably growing skepticism from Congress is at least partially due to the reports issued in 2005 by GAO and the CBO. In February of 2005, the CBO observed that “[b]ecause the FCS program is still in the early stages of development, its full costs are not yet known.”¹² One of the options put forward by CBO in the same report called for cancelling the FCS program (except for a “residual research and development effort to explore promising technologies for later use in existing systems”).¹³ The only other option explored in depth by this CBO report involved the delay of FCS fielding from 2011 to 2015, and would “reduce funding accordingly.”¹⁴ This proposed CBO option was similar to the four-year fielding delay that the Army announced in July 2004.

⁹ H.R. Rep. No. 108-553, 2004.

¹⁰ Stephen Daggett and Amy Belasco, *Authorization and Appropriations for FY2005: Defense*, Washington, D.C.: Congressional Research Service, RL32305, December 14, 2004.

¹¹ H.R. Conf. Rep. No. 108-622, 2004.

¹² Congressional Budget Office, *Budget Options*, February 2005, at Sec. 3, p. 2.

¹³ Congressional Budget Office, *Budget Options*, Sec. 3, p. 3.

¹⁴ Congressional Budget Office, *Budget Options*, Sec. 3, p. 2.

The GAO's comments on FCS in early 2005 include:

- “The program is not appropriately applying best practices to maturing its critical technologies.”
- “The Army is holding FCS technologies to a lower maturity standard than best practices and DOD policy calls for. This increases the risk of program cost growth and schedule delays.”¹⁵

These criticisms echo ones from earlier GAO reports and testimony before Congress in prior budget cycles.

Hearings on Capitol Hill in March 2005 before both the House and Senate Armed Services Committees gave GAO Director of Acquisition and Sourcing Management, Paul Francis, opportunities to further explain GAO's take on FCS to members of Congress. Claude Bolton, Assistant Secretary of the Army for Acquisition, Logistics, and Technology, appeared (among others) on behalf of the Army at these hearings. At the House hearing before the Tactical Air and Land Forces Subcommittee, representatives were given two sharply contrasting pictures of how the FCS program was progressing. According to Francis' testimony:

- “The FCS program faces significant challenges in setting requirements, developing systems, financing development, and managing the effort. It is the largest and most complex acquisition ever attempted by the Army.”¹⁶
- “[E]ven with [2004 program restructuring], the FCS is still at significant risk for not delivering planned capability within budgeted resources. This risk stems from the scope of the program's technical challenges and the low level of knowledge demonstrated thus far.”¹⁷
- “There is not enough knowledge to say whether the FCS is doable, much less doable within a predictable frame of time and money. Yet making confident predictions is a reasonable standard for a major acquisition program given the resource commitments and opportunity costs they entail. Against this standard, the FCS is not yet a good fit as an acquisition program.”¹⁸

In the face of this GAO criticism, Bolton's testimony in the same hearing indicated that FCS was, according to the Army's earned value management system (EVMS), per-

¹⁵ Government Accountability Office, *Assessments of Selected Major Weapon Programs*, Washington, D.C.: Government Accountability Office, GAO-05-301, March 2005.

¹⁶ Government Accountability Office, *Future Combat Systems Challenges and Prospects for Success*, Statement of Paul L. Francis, Director, Acquisition and Sourcing Management, Washington, D.C.: Government Accountability Office, GAO-05-428T, March 2005, p. 7.

¹⁷ Government Accountability Office, *Future Combat Systems Challenges and Prospects for Success*, 2005, p. 12.

¹⁸ Government Accountability Office, *Future Combat Systems Challenges and Prospects for Success*, 2005, p. 24.

fectly adhering to budget, schedule, and performance requirements established since the program contract was formed.¹⁹

The Senate Airland Subcommittee of the SASC held a hearing on FCS at nearly the same time. In early 2005, Senator John McCain became chair of the subcommittee. In 2004, McCain had successfully challenged Boeing's plan to lease, rather than sell, refueling tankers to the Air Force at a cost of \$23 billion. McCain's leadership in the Boeing tanker case uncovered evidence of unethical behavior and led to two Boeing executives pleading guilty to criminal charges.²⁰ McCain's subcommittee hearing, like the House one, featured testimony from Paul Francis and Claude Bolton, among others.

McCain focused the hearing on (1) the use of OTA to contract for FCS, and (2) the designation of Boeing as co-Lead Systems Integrator (LSI). One witness, Ken Boehm, chairman of the National Legal and Policy Center, summarized his position on the two matters thusly:

The best recommendation I can say at this point, where Boeing is already in as LSI, we're already under way, is this: I don't see any alternative to Congress intensifying its oversight, because the oversight is lacking in the arrangement that's under hand ... The most ethically challenged Defense contractor in the country is now in charge of the most expensive high-risk Defense program, using an agreement that minimizes oversight and accountability. If that doesn't call for increased oversight, what does?²¹

Claude Bolton struggled to justify the use of an OTA contract (which, in the case of FCS, excluded provisions from the Procurement Integrity Act (PIA) and the Truth in Negotiations Act (TINA)) in the face of thorough questioning from McCain. Bolton testified at the hearing that Boeing's prices are certified as fair under the OTA, even though it excludes TINA, which is the FAR contract provision under which contractor prices typically would be certified as fair. After the hearing concluded, however, the *Washington Post* reported that "the Army told the committee that the contract does not require certification."²²

As stated above, Congress increased its scrutiny of FCS after the GAO and CBO reports and after the House and Senate subcommittee hearings. The *Wall Street Journal* reported on April 6, 2005 that "[c]apping months of internal Army deliberations, escalating cost projections and rising concerns on Capitol Hill, the Army said it will

¹⁹ U.S. House of Representatives, *Future Combat Systems: Hearing Before the Subcommittee on Tactical Air and Land Forces*, Washington, D.C.: U.S. Government Printing Office, March 16, 2005.

²⁰ Renae Merle, "Hearings Focus on \$100 Billion Army Plan," *Washington Post*, March 15, 2005a, p. E10.

²¹ U.S. Senate, *Army Transformation and the Future Combat System in Review of the Defense Authorization Request for FY 2006*, Washington, D.C.: U.S. Government Printing Office, March 16, 2005.

²² Renae Merle, "McCain, Auditors Question Army Modernization Effort," *Washington Post*, March 17, 2005b, p. E2.

convert the contract from . . . [OTA] to a standard contract with full safeguards and ‘managerial improvements.’”²³ The article explains that “[a]s scrutiny of FCS mounted on Capitol Hill, the Army underwent big changes. Most champions of the original FCS concept that gave Boeing wide latitude resigned or moved to other duties.”²⁴

The Army announced in April 2005 that it would change the FCS contract from OTA to a standard FAR one. The FY06 NDAA—which became law on January 6, 2006—included a provision ordering the Secretary of the Army to procure FCS “through a contract under part 15 of the Federal Acquisition Regulation.”²⁵ The FY06 NDAA also mandates that GAO submit annual reviews of FCS to Congress until completion of the program’s systems development and demonstration phase, and the law lists the specific matters that must be included in each annual GAO report.

As noted above, the SAC joined both relevant House committees in recommending cuts to the FCS budget for FY06, albeit small ones relative to those proposed by the House committees. The SAC report stated that the committee was “concerned with the amount of program overhead and management reserve included in the FCS budget. Of note, the budget request includes over \$100,000,000 for the purpose of program withholds and ‘other’ taxes contrary to normal budget practices, including funds in anticipation of congressional reductions.”²⁶ Interestingly, this language and the dollar amount are practically identical to that found in the HAC Report for FY05, quoted above.²⁷ The SAC suggested cutting this \$100 million, while the House committees each identified about \$400 million in cuts.²⁸ As noted in the December 2006 SAR, the appropriations process for FY06 ultimately resulted in a \$236 million decrement for FCS. Even with the decrement, however, FY06 funding for NLOS-C was \$40.8 million above the Army’s budget request.²⁹ This was meant to ensure that fielding of NLOS-Cs would begin in 2008.

FY07

FCS budgeting for FY07 involved further heightening of congressional oversight and scrutiny, resulting in a greater funding decrement (\$319.1 million) than in each of the

²³ Jonathan Karp and Andy Pasztor, “About-Face: Army Changes Strategy; Revamping of Boeing Deal Shifts Service’s Philosophy of Relying on the Industry,” *Wall Street Journal*, April 6, 2005a, p. B2.

²⁴ Karp and Pasztor, 2005a.

²⁵ Public Law 109-163, National Defense Authorization Act for Fiscal Year 2006, January 6, 2006.

²⁶ S. Rep. No. 109-141, 2005.

²⁷ See H.R. Rep. No. 108-553, 2004. This suggests that the submitted budget justification materials for FCS had not changed from the prior year.

²⁸ See H.R. Rep. No. 109-119, 2005.

²⁹ H.R. Conf. Rep. No. 109-359, 2005.

prior two budgets. In the period leading up to this decrement, GAO and CBO reports and hearing testimony stressed the same points that they had in prior years: FCS technologies were not maturing fast enough, and budget estimates continued to grow.³⁰ In March 2006, GAO estimated the total cost of the FCS program to be \$160.7B—76 percent greater than the Army’s initial estimate.³¹ Regarding the growing budget, the SAC noted in July of 2006 that

[t]he [June 2006] estimate prepared by . . . [CAIG] projects FCS life cycle costs of approximately \$300,000,000,000 in fiscal year 2003 constant dollars. The estimate is 75 percent higher than an estimate prepared by the CAIG just three years ago.³²

At the same time as FCS was experiencing growth in cost estimates, cost estimates associated with Army modularity were also increasing, from \$20B in January 2004 to \$52.5B in March 2006.³³ Navy shipbuilding and missile defense were repeatedly brought up in hearings as experiencing cost growth that potentially threatened the FCS budget.³⁴

The House Committee on Armed Services directly followed a recommendation from GAO³⁵ in requiring FCS to undergo a “go/no-go review” by September 2008.³⁶ This requirement made it into the FY07 NDAA, although the timing of the go/no-go decision was changed in the law to “not later than 120 days after the [FCS] preliminary design review.”³⁷ The House Committee on Appropriations cited the GAO in its June

³⁰ See John M. Donnelly, “Dream Army’s Rude Awakening,” *CQ Weekly*, July 31, 2006, p. 2100.

³¹ Government Accountability Office, *Business Case and Business Arrangements Key for Future Combat System’s Success*, Statement of Paul L. Francis, Director, Acquisition and Sourcing Management, Washington, D.C.: Government Accountability Office, GAO-06-478T, March 2006.

³² S. Rep. No. 109-292, 2006.

³³ U.S. House of Representatives, *Future Combat Systems, Modularity, and Force Protection Initiatives: Hearing Before the Subcommittee on Tactical Air and Land Forces*, Washington, D.C.: U.S. Government Printing Office, April 4, 2006.

³⁴ U.S. House of Representatives, 2004. See, for instance, Subcommittee Chairman Curt Weldon’s opening remarks:

With all the requests not just to this subcommittee, but the need to increase our shipbuilding accounts, the need to fund missile defense, the need to take care of quality of life issues, the need to fund new aviation programs and there tactical fighters are being asked for, as well as the helicopter programs. And therefore we have to as much as and as aggressively as possible ask the tough questions on where we’re going budget-wise.

³⁵ Government Accountability Office, *Business Case and Business Arrangements Key for Future Combat System’s Success*, 2006.

³⁶ H.R. Rep. No. 109-452, 2006.

³⁷ Public Law 109-364, John Warner National Defense Authorization Act for Fiscal Year 2007, October 17, 2006.

2006 report to support the assertion that “the program has not achieved the mature technologies and firm requirements that should have been achieved three years prior.”³⁸

Conclusion

Legislative history regarding FCS funding decrements in FY05–FY07 shows Congress becoming increasingly influenced by GAO and other auditors outside the program, which were highly critical of the FCS program. Led by the House Armed Services and Appropriations committees, Congress demanded more oversight of FCS year to year. Results of Congress following GAO recommendations include Congress demanding more independent, outside assessments of FCS progress, and the program altering the FCS contract to include TINA and PIA provisions (this change was later codified in the FY06 NDAA). Other results of criticism from GAO and other auditors include Congress increasing the number of FCS program elements (in order to increase congressional control and oversight), and the funding decrements.

Portions of each decrement were explained in committee reports as having been identified as “other’ taxes,” “program withholds,” or “overhead.” Other than the identification of these categories as improper, no explanation is available in the legislative record for why the relevant authorization and appropriation acts cut the amounts they did. Also, no explanation from the Army has been found to account for the fact that the submitted FCS budget in FY06 contained a request for “other’ taxes” and “program withholds,” after Congress explicitly indicated its disapproval of including such categories during the budgeting process for FY05. Indeed, the Army had heard from Congress as early as in 2003 that its submitted FCS budget justification materials were insufficient.³⁹ The apparent failure of the Army to correct this mistake indicates that the program did not always sufficiently respond to congressional feedback, even as Congress was decreasing FCS funding.

The congressional interest in FCS and decrements through those years were raised often in interviews with past FCS officials. GAO audits of FCS were described as “self-fulfilling prophecy” and a “death spiral.” Audits led to cuts, which led to setbacks within the program, which led to more problems identified in subsequent audits—and so on. The GAO was faulted by some officials as having no strategic incentive to positively review an acquisition program. To some, FCS was simply a good target for cuts because it was large.⁴⁰

³⁸ H.R. Rep. No. 109-504, 2006.

³⁹ See H.R. Conf. Rep. No. 108-283, 2003.

⁴⁰ See H.R. Conf. Rep. No. 108-283, 2003.

FCS Requirements Data and Methodology

Driving FCS was one of the largest bodies of requirements ever developed. This has important implications for research, since the inordinate size of the dataset required a number of analytical tradeoffs to parse the data. For instance, there was a fairly discrete set of core conceptual studies, including the Army Vision and several versions of the Organizational and Operational (O&O) Plan, which flowed into a larger but still manageable set of operational requirements. As the requirements flowed down from the Operational Requirements Document (ORD) into System of System Specifications (SoSS) and Prime Item Development Specifications (PIDS), which describe the technical characteristics of the collective set of systems and the individual systems and subsystems themselves, respectively, the dataset becomes increasingly large, complex, and difficult to parse comprehensively.

In April 2003, for instance, when FCS passed Milestone B, the JROC-approved ORD consisted of 560 requirements.¹ This number decreased slightly over the next few years, down to 541 ORD requirements by FY08, as TRADOC and the LSI decomposed, refined, and eliminated or condensed some requirements. But the number of lower-level requirements, such as SoSS, multiplied exponentially from 580 in April 2004 to roughly 11,000 by late May 2008, while the number of PIDS exploded from 1,133 to approximately 55,000 over the same four-year period.² According to a May 2008 briefing by the LSI, the program office expected the Dynamic Object-Oriented Requirements System (DOORS), the FCS program-wide database for tracing and tracking requirements, to contain over 300,000 requirements in all, from system specs to specs for hundreds of individual subsystems.³

Because the dataset mushroomed in both size and complexity as the FCS program progressed, the scope of our analysis became more focused over time, as we

¹ UAMBL, "ORD Block Diagram (Linked)," unpublished Excel spreadsheet, April 14, 2003.

² Boeing and SAIC, "SoSS Workshop," unpublished briefing slides, Huntington Beach, Calif., April 12–23, 2004; "Future Combat Systems (Brigade Combat Team) Deep Dive," unpublished briefing slides, briefing to MG Charles A. Cartwright and Mr. Gregg Martin, May 31, 2008.

³ Boeing and SAIC, "SoSS Workshop," 2004; "Future Combat Systems (Brigade Combat Team) Deep Dive," 2008.

zeroed in on an increasingly narrow set of important requirements rather than grapple with the complete set of requirements and engineering specifications. As a result, while we were able to assess essentially the complete set of conceptual and operational documents, drafts, and various changes to those documents, including several versions of the Unit of Action O&O Plan and the ORD, it was impossible to replicate the same degree of thoroughness with lower-level requirements, such as system specs and PIDS. We also were unable to access DOORS, which may have allowed us to analyze a greater amount of data more faithfully and yielded additional insights. However, by identifying several important high-level requirements in the ORD as case studies, and by tracking them as they were decomposed, we have been able to develop a reliable understanding of the full range of requirements and their role in the FCS program. We also interviewed dozens of officials involved with FCS at all levels and stages of the process, including requirements personnel, program managers, and engineers engaged in decomposing requirements, understanding them, and translating them into designs and materiel solutions.

Selected Technology Transfer Agreements Between PM FCS and Army S&T

Table on following pages.

Technology	S&T Command	S&T Program	Signature Date	Risk	CTE	Deliverables
P&E HWIL SIL	TARDEC	ATO Hybrid Electric FCS; III.LG.2004.03, ATO Pulse Power for FCS; III. GC.2004.02, High Power Li-Ion Batteries; MTO 03-06, Silicon Carbide (SiC); MTO-03-08	May 06	MGV006, MGV 0078, MGV0126, MGV0125, and MGV0243	20A - High power density engine	Test report for advanced diesel engine generator; reconfigurable thermal management system development integration and testing; integrate and test pulse forming network; test for various power converters
Advanced Lightweight Track Program ATO-D	TARDEC	Advanced Lightweight Track Program ATO-D; III. GC.2006.02,	May 06	MGV0002	none	Test results for segmented band track and fully passive advanced track tensioner
Head Tracked Sensor Suite (HTSS) ATO III.SE.2002.02	CERDEC	Head Tracked Sensor Suite (HTSS) ATO III. SE.2002.02	May 06	NA	none	Hardened prototype gimbal mounted array of sensors; user interface/human factors insights for use of MWIR and SWIR
High energy density power conditioning capacitors	ARL	HED Capacitors ATO-M	Mar 09	MGV0243 (Propulsion inverter maturation) and MGV0126 (fuel efficient hybrid electric propulsion)	31 - High density packaged power	High temperature and energy density power conditioning capacitors
Active protection systems	RDECOM, TARDEC, CERDEC, AMRDEC, ARDEC, AMSAA	Kinetic Energy Active Protection System ATO and the Infrared Cueing System (ICS) ATO	Jun 06	FCS Risks 71 and 127	25A - APS, 25B- APS Threat Warning Sensor	Cueing sensor design, algorithms to classify threats and handoff to APS tracking, design of interceptor, analysis/simulation of KE-defeat effectiveness
Armor	RDECOM	Affordable Structural and Appliqué Armor Manufacturing Technology Objective (MTO) (ARL-MTO-03- 07).	Jun 06	MGV0083, and MGV0191	none	Manufacturing line for SiC armor tiles, techniques for hybrid mine blast protection floors and B-kits, fabrication demo of upper and lower hull
Battle command for UGV, UGS, and UAV	RDECOM	Networked enabled C2 of Robotic Entities (C2ORE)	Apr 06	NA	18 - Distributive Collaboration of Manned/ Unmanned Platforms; 10 - Decision Aids and Intelligent Aids	Design and experimental reports of BC software for planning/placement, monitoring, execution of UGS, UAV, UGV

Technology	S&T Command	S&T Program	Signature Date	Risk	CTE	Deliverables
RSTA with LD payload for DARPA Organic Air Vehicle II	RDECOM	MEP for Class II UAV III. SE.2004.03	Apr 06	NA	none	Prototype and trade studies
Network-Centric Managed Connector (NCCM) software	RDECOM	Network Enabled Command and Control (NEC2) Army Technology Objective (ATO) development program - Network Enabled Battle Command (NEBC) work package	Jun 07	NA	none	NCCM software for data throttling, policy-driven QoS, etc.
Crew station and robotics collaboration	TARDEC and ARL	D.UN.2006.02 Robotics Collaboration Army Technology Objective (ATO)	Feb 07	UGV0068 and UGV0213	18 - Distributive Collaboration of Manned/ Unmanned Platforms	SME for crew station issues, trade studies, models, experiment reports
ARV technologies	TARDEC	ATO [D] III.GC.2006.04 Near Autonomous Unmanned Systems	Jan 08	NA	NA	Sensor integration and trade study, experimental reports, software
Robotic technologies	TARDEC and ARL	Semi-autonomous Robotics for FCS STO; Robotic Follower ATD, Crew Automation Test Bed ATD; ARV Technology STO, Human Robot Interaction STO	Mar 04	NA	18 - Distributive Collaboration of Manned/ Unmanned Platforms	
MANET operation software for FCS Network Management System	CERDEC	IV.BC.2000.01 Dynamic Addressing and Management for the Army (DRAMA) ATO	Apr 06	NA	4 - MANET protocols; 10-Decision Aids/ Intelligent Agents	Various network operating software for integration with for network management software

Technology	S&T Command	S&T Program	Signature Date	Risk	CTE	Deliverables
Sensor-shooter pairing algorithms	RDECOM	(STO) III.EN.2002.04, also known as the Fire Control-Node Engagement Technology (FC- NET) common Technical Fire Control Architecture (TFCA)	Jun 04	NA	14 - Dynamic Sensor-Shooter Pairing Algorithms & Fire Control Critical Technology Area	Management and execution of FC-NET STO
UGV target identification sensors and integration	RDECOM	Networked Sensors for the Future Force (NSfFF) ATO	Mar 07	UGV sensor integration cost	none	Program specifications and lessons learned
Sensor integration for MGV	RDECOM	III.SE.2005.03 Distributed Aperture System ATO	May 06	MGV146 (Common Crew Station Risk or Vehicle Motion Effect Risk)	none	Demonstration reports, prototype, and full system
Measured effectiveness of reducing laser susceptibility of un-cooled IR sensors	RDECOM	Low Cost Counter-Reconnaissance Technology ATO	May 06	C4ISR watch item 110	26-	Analysis reports
High power density engine	TARDEC	High Power Density Engine S&T	Nov 05	NA	20A -	Test results of surrogate 4-cylinder engine, modeling of 5-cylinder engine results
Manufacturing process for high power batteries	TARDEC	Energy Storage Manufacturing - Very High Power Batteries, MTO-03-06	Jun 08	MGV0078	31 - High Density Packaged power	Manufacturing process
SME and management for lightweight cannon recoil technologies	ARDEC	FCS 120mm LOS BLOS System ATD	Mar 04	NA	17-Lightweight recoil management	SME, security classification guides, data rights
BC software/hardware, autonomous navigation system, and large UGV testbed	TARDEC	Robotic Vehicle Control Architecture for FCS ATO D.UN.2008.01	Jun 09	FCS priority matrix items 2a/3b	none	ANS, BC software, SoSCOE feedback

Technology	S&T Command	S&T Program	Signature Date	Risk	CTE	Deliverables
Network intrusion detection system	CERDEC	Tactical Wireless Network Assurance (TWNA) STO	Mar 04	NA	3B2- Security Systems and Algorithms	Intrusion Detection Sensor/ System
Silicon carbide power electronics for MGV and manufacturing capabilities	RDECOM, TARDEC, ARL	Silicon Carbide Power Electronics ManTech (ATO-M.AL.2003.08)	Mar 09	MGV0243 (Propulsion inverter maturation) and MGV0126 (fuel efficient hybrid electric propulsion)	20B -	Devices and power modules for MGV power electronics
SUGV sense thru wall sensors	RDECOM	Suite of Sense Through the Wall (STTW) System ATO III.SE.2004.04	Apr 06	NA	none	STTW prototype for integration with SUGV
Ground based AiTR with LWIR and SWIR imagers	RDECOM	Target Acquisition Sensor Suite (TASS) ATO III. SE.2003.05	Apr 06	C40081 Multi-Spectral Sensors and Seekers, C40129 AiTR for RSTA	none	Evaluation of SWIR and SWIR for AiTR
Communication antennas	RDECOM	Tactical Network and Communications Antennas (TNCA) ATO (D.C4.2006.04)	Jun 07	C40115- HNW Performance	1C-WIN-T	Various types of antenna
Technology generating water from exhaust	RDECOM	Water Purification Technology, ST IV.LG.2000.04	Mar 04	NA	22A- Water generation and purification	Prototype hardware, SME, reports
Laser protection for MGV drivers and sensors	TARDEC	Vision Protection ATO	May 06	NA	NA	Test results

Where the FCS Systems Are Today

In this report we considered the ambitious technology development effort undertaken by FCS in terms of the novelty of multiple critical technology elements, broad use of complementary programs and Army science and technology, and other aspects commonly found in programs but challenged by the complexity of SoS acquisition, such as modeling and simulation, analysis, testing, and risk management. With such a large-scale effort, intended to realize the Army's modernization strategy, what technology outputs were borne of the program?

A previous section showed that of the 44 remaining CTE, 36 were rated at technical readiness level 6 in 2009 by the ASA(ALT)'s IRT, achieving the DoD recommended maturity standard for entrance into Milestone B, despite maturing at slower rates than expected, and in some instances being reevaluated at lower maturity than initially assessed. Of the 18 systems comprising the 18+1+1 SoS, each went through a system PDR in preparation for a SoS PDR that occurred prior to the program's cancellation. One of the systems, NLOS-LS, also completed a CDR in 2006.¹ When FCS was restructured in 2009 by Secretary Gates,² the 18 systems ended in disparate states, with some producing actual prototypes or fielded systems, and others remaining in the design stage. This appendix describes each of the 18 systems as well as their status at the end of the program.

FCS Technology Expertise and Acquisition Processes Add Value to the Army

FCS furthered technology development and expertise in several areas represented by CTE, CP (e.g., JTRS GMR and HMS, GSTAMIDS and ASTAMIDS), and more generally improving acquisition enablers, like M&S. These areas are diverse and impact

¹ Briefing on FCS NLOS-LS System, demonstrated capabilities and schedule. Not available to the general public.

² Department of Defense, *Future Combat System (FCS) Program Transitions to Army Brigade Combat Team Modernization*, No. 451-09, Washington, D.C., June 23, 2009.

a wide breadth of Army interests, such as network warfare, logistics, M&S collaboration across commands, and robotic vehicles. In the area of network warfare, our interviews have indicated a paradigm shift within the Army that now appreciates “networks” more holistically rather than just “radios” to provide information assurance that enable network warfare concepts. A National Academies study concludes that within the Army, the FCS program developed network science, technology and experimentation more comprehensively than any other acquisition program.³ The program’s dependence on advanced networking concepts motivated significant development of MANET science⁴ and technology, including commercial ventures,⁵ which may not have progressed as such without the scale of the FCS effort. The Army’s CERDEC has also developed greater expertise in networking for the future force through collaboration with industry.⁶ FCS emphasis on net-centric operations has also benefited logistics operation in the Army, by producing three software applications⁷ presently managed by PEO(I). These sustainment technologies will provide critical logistics data defined by the warfighter as crucial for modernization.⁸ FCS also relied heavily on M&S, which is conducted by several organizations within the Army that may not coordinate these activities. The Cross-Command Collaborative Effort or 3CE, was created to share M&S capabilities, assumptions, and results across TRADOC, ATEC, RDECOM and the LSI.⁹ Another area greatly emphasized in FCS were robotic capabilities through UGV systems such as the MULE, which has spawned a variant called the SMSS that continues to be field tested by the Army.¹⁰ All of these areas are a representative selection of technologies resulting from FCS, emphasized by program officials in our interviews.

³ Committee on Strategies for Network Science, Technology, and Experimentation, National Research Council, *Strategy for an Army Center for Network Science, Technology, and Experimentation*, Washington, D.C.: The National Academies Press, 2007.

⁴ DARPA has funded various academic institutions to develop fundamental results for a MANET through its ITMANET program. DARPA, *Information Innovation Office*, no date.

⁵ For example, CoCo Communications Corp. provides MANET enabled handheld devices, tablets, and laptops. CoCo Communications Corp., *MANET/Mesh Enabled Devices*, no date.

⁶ An instance of such collaboration is the development of “NEDAT,” computer simulation tools to design and analyze future force networks, developed jointly by CERDEC and Telecordia Technologies. Latha Kant et al., “NEDAT: A Toolset to Design and Analyze Future Force Networks,” in *Proceedings of the Military Communications Conference (MILCOM)*, San Diego, Calif.: November 2008.

⁷ LDSS, PSMRS, and LDMS, which are discussed further in this section.

⁸ Thomas Hosmer, “Sustainment Technologies for BCT Modernization,” *Army Sustainment*, Vol. 43, No. 1, January–February 2011.

⁹ “Cross-Command Collaboration Effort (3CE),” October 3, 2008, Approved for Public Release—Case GOVT 08-8101.

¹⁰ SMSS is deployed with troops in Afghanistan to see how autonomous robots can benefit the Warfighter. See Lockheed Martin, *SMSS*, no date.

Invariably these outputs will exist at a variety of developmental stages in their end-state, some as design drawings or simulation models, and others as prototypes with test data. There has been no complete accounting of FCS technologies and systems, and it remains certain that some technologies and efforts from FCS will be lost because of that. One possible strategy to remedy this situation is to create a checklist based on the AMSAA System Book,¹¹ which served as the official reference to key technologies and capabilities associated with FCS systems for mission-level analysis of SoS. These capabilities can then be catalogued by associated deliverables, end-state status (simulation model, prototype, etc.) and present ownership (PEO, PM, or contractor).

FCS Systems: Description and Status at Cancellation

To go beyond anecdotal accounts of select outputs, the Army will need a concerted effort to collect those technologies it deems particularly valuable. Nonetheless, in this appendix we have collected a number of examples, including all 18 systems, to help illustrate the fate of the FCS technology development effort. We also discuss a particular effort to capture lessons, the MGV Book of Knowledge, that will be used by the ground combat vehicle (GCV) contractors to leverage FCS experience of vehicle design. Furthermore, we consider whether similar efforts would be useful for the other FCS systems based on their relevance to future Army acquisitions.

The Eight Manned Ground Vehicles

In addition to the various unmanned platforms (UGV, UAS, UGS, IMS, NLOS-LS), the FCS family of systems had eight variants of manned ground vehicles (MGVs) derived from a common chassis but serving specific operational functions. The variants progressed at different rates, with a stated goal of 80 percent commonality amongst them, partly due to special program status conferred on the Non Line of Sight Cannon, which required fielding by FY10.¹² The MGV family made it to a preliminary design review, which was held January 19–23, 2009, and led by the MGV IPT and attended by other IPT's including: C4ISR, SDSI, LRR, UAV, UGV, and TNG.¹³ The MGV technical baseline, which supported the preliminary design configuration, was based on a top-down, systematic approach with common architectures of vehicle electronics, physical design, software integration, and thermal management. The technical base-

¹¹ U.S. Army Materiel Systems Analysis Activity (US AMSAA) "Army Future Combat Systems Unit of Action System Book," v.3.02, March 22, 2003.

¹² John Young, USD(AT&L), "Non-Line of Sight—Cannon (NLOS-C) Special Interest (SpI) Program Acquisition Decision Memorandum," memorandum for the Secretary of the Army, December 1, 2007.

¹³ Ernie Wattam and COL Bryan McVeigh, "MGV PDR—Executive Outbrief," MGVI IPT Directors, February 11, 2009.

line consists of specifications and interface documents for each of these architectures, resulting in over 450 graded documents that would eventually form the basis of the follow-on GCV program's Book of Knowledge.¹⁴ The PDR closed 73 criteria with 10 remaining (8 with critical action items), estimated to be completed by the end of March in 2009. Overall, the MGVI IPT concluded that the schedule for CDR was executable.¹⁵ The PDR also recognized several limitations of the MGVI design as related to requirements, listed in Table E.1.

Other limitations include fuel transfer timelines between MGVs, water supply and rations, and limitations specific to particular MGVI variants. Not all technical performance measures (TPM) fell short of the required capabilities; most TPM dealing with firing rates, range, and accuracy were exceeded by the NLOS-C, NLOS-M, MCS, and ICV.

Active Protection System and the related threat-warning sensor, critical technology elements for the program, were specifically highlighted as program-level risks with a medium rating for likelihood of occurrence and consequence. Although not articulated, the MGVI executive brief states that risk mitigation plans for these items were "producing positive results," while the other CTE associated with MGVI posed less risk and had been effectively mitigated. To demonstrate production readiness, the MGVI IPT used engineering manufacturing readiness levels to judge risk for a variety of categories: design producibility, processes, tooling, design to cost, materials, technical,

Table E.1
Manned Ground Vehicle Status and Requirements at PDR

Category	Requirement	Capability at PDR
Sustained highway speed	80 km/h (full combat configuration)	60–68 km/h (with AT mine kit)
Cross-country speed	45 km/h	32–37 km/h
Acceleration 0–48 km/h	10.5 s	12.3–14.4 s
Range	400 km	300–385 km
Transportability	3 on C-17	2 with AT mine kit
Silent watch	2 hours	2–5 minutes
Maintenance ratio	0.05	0.082–0.11
Mean time between system aborts	512–540	399–578
Mean time to repair	0.5	0.83–1.11
% crew chief repairable	80%	24%–41%
Reverse obstacle height	1 m	0.7 m

NOTE: TARDEC Battery data, Army S&T, no date. No title or author. Not available to the general public; interview data.

¹⁴ Interview data.

¹⁵ Wattam and McVeigh, 2009.

and facilities. The overall score showed very little risk (0.94 out of 1.0) for production, with improvements required in producibility and tooling due to design maturity. The lessons learned from the MGV PDR that were highlighted as key to its success were the plans outlined for the review, primarily by the chief engineers in various organizations (PM/LSI/OTP), definition of artifacts controlled by the MGV decision board, a series of earlier reviews, and leveraging input from SoS engineering. Affordability studies showed a forecasted average unit procurement cost (AUPC) for MGV of \$1,859 million, under target expectations of \$1,866 million. Compared to current force vehicles (Abrams, Bradley, Paladin, Stryker, M113A3, and MRAP), the MGV was more capable than each one in most TPM, but not all (Figure E.1).¹⁶

Non Line of Sight Cannon (NLOS-C)

It is worth highlighting the NLOS-C because it is the MGV variant to make the most developmental progress, eventually producing five prototypes. Such progress was due to its special program status and required earlier fielding date relative to the other MGV. DoD Appropriation Acts for FY05/06/07 required the Army to field NLOS-C by FY10, independent of the broader FCS timeline, and was thus designated an ACAT 1 Special Interest (SpI) program.¹⁷

The NLOS-C (Figure E.2) was a two-man ground vehicle with networked, extended-range targeting developed by BAE Systems, using a 155mm howitzer cannon as its primary armament.¹⁸ Prior to developing an NLOS-C prototype, BAE developed an NLOS-C “Concept Technology Demonstrator” as a proof of principle testbed to demonstrate the possibility of the eventual platform.¹⁹ The CTD completed testing in early 2006, and transferred various technologies to the NLOS-C prototypes.²⁰ Five prototypes were developed and were at various stages in 2009 (Table E.2).²¹

Due to the legal status afforded to the NLOS-C, its eventual cancellation occurred after the other MGV variants in December 2009.²² Acquisition Chief Carter explained that the Pentagon does not believe that funding the cannon is in “the taxpayer’s best interest at this time,” and issued a memo to replace the capability with the Paladin Improvement Program (known as PIM).²³ Some technologies were adopted in the

¹⁶ Wattam and McVeigh, 2009.

¹⁷ Young, 2007.

¹⁸ “FCS Smart Book,” October 2008 FCS 081014_08smartbook.pdf

¹⁹ BAE Systems, *NLOS-C Concept Technology Demonstrator FAQs*, 2008.

²⁰ BAE Systems, 2008.

²¹ Fasi Sharafi (MGV Gov. Chief Engineer) and Robert Woods (MGV LSI Chief Engineer), “MGV Platform Review,” circa February 2009. Not available to the general public.

²² Daniel Wasserbly, “US DoD Terminates NLOS-C Programme,” *Jane’s Defence Weekly*, December 11, 2009.

²³ Wasserbly, “US DoD Terminates NLOS-C Programme,” 2009.

Figure E.1
Technical Performance Measures of FCS MGVS vs. Existing Army Vehicles

TPM Topic	Abrams (M1A2)	Bradley (M2A3)	Paladin (M109A6)	Stryker MGS	M113A3 FOV	MRAP
Supply Cross-Leveling Time (minutes) Fuel = ↑ Ammo = ↔	↑	↑	↑	↑	↑	
Maintenance Ratio (MR) (MMW/CH)	↑	↑	↑	↑	↑	
Mean Time Between Sys Abort (MTBSA) (hrs)	↑	↑	↑	↑	↑	
Mean Time to Repair (MTTR) (hrs)	↑	↔	↑	↓	↔	
Platform Availability (Ao)/(OR rates)	↔	↓	↑	↓	↑	↔
Sensor Range Performance	↑	↑	↑	↑	↑	
Crew Protection (Mine)	↔	↑	↑	↑	↑	↓
Crew Protection (RPG, ATGM, HE/HEAT)	↑	↑	↑	↑	↑	↑
Crew Protection (14.5/30 MM 60 Deg Arc.)	↓	↑	↑	↑	↑	↑
Integrated Platform Weight (lbs)	↑	↑	↑	↓	↓	↓
Sustained Speed, Highway (km/h)	↔	↔	↔	↓	↔	↓
Sustained Cross-Country Speed (km/h)	Not available	Not available	Not available	↑	Not available	↑
Dash Speed 0-48 (seconds)	↑	↑	↑	↓	↑	↓
Indirect Fire CEP (%)			↑			
Indirect Fire CEP (meters)			↑			
Primary Armament BLOS Stationary Accuracy (%) (if it meets req it's 100%)	↑					
Primary Armament Accuracy (%) (if it meets req it's 100%)	↔	↔	↑	↔ _M	↑ _M	↑
Max firing range (kilometers)	↑		↓	↑ _M	↑ _M	
Max rate of fire (rounds per minute)			↑	↔ _M	↑ _M	
Emplace response time (seconds)			↑	↑ _M	↑ _M	

MGVS more capable
 MGVS less capable
 Equal capability
 Not applicable

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PIM program, including the 600V electric drives (elevation and traverse drives) and 600V electric rammer. Rather than leverage the NLOS-C, senior Army officials indicated that legacy mobile howitzers would be a part of PIM with new chassis, fire con-

Figure E.2
NLOS-C



RAND MG1206-E.2

Table E.2
Status of NLOS-C Prototypes

Prototype #	2009 Status of Prototype
1	Completed stability assessments Jan 09, starting safety testing week of 9 Feb 09
2	Completed MS C testing, entering final integration
3	Mission Module and Chassis assembly and integration ongoing
4	Chassis integration complete, integrating mission module
5	Mission Module and Chassis assembly and integration ongoing

trol systems, and engines.²⁴ BAE Systems unveiled its upgraded 155mm PIM shortly thereafter.²⁵

In Table E.3 we summarize the status of the other seven MGV variants, which were only in the design phase and were all cancelled in April 2009.²⁶ Recall, however, that an MGV system-level PDR did occur in January 2009. Note that both the RSV

²⁴ Wasserbly, "US DoD Terminates NLOS-C Programme," 2009.

²⁵ Daniel Wasserbly, "BAE Systems Unveils Modernised Howitzer Vehicle for US Army," *Jane's Defence Weekly*, January 22, 2010.

²⁶ Department of Defense Memorandum No. 451-09, *Future Combat System (FCS) Program Transitions to Army Brigade Combat Team Modernization*, June 23, 2009.

Table E.3
MGV Variants and Their Status at Program Cancellation

MGV Variant	Developer ^a	2009 Design Status Highlights ^b
Reconnaissance & Surveillance Vehicle (RSV)	General Dynamics	Continuing to mature RSV design to CDR. Maturing SIGINT integration approach.
Mounted Combat system	General Dynamics	Tested the firing platform on TARDEC's turret motion base simulator from July to Nov 08.
NLOS Mortar ^c	BAE Systems	NLOS-M Firing Platform has fired 1178 rounds. Mortar Ammunition Handling System in process of being assembled.
Field Recovery & Maintenance Vehicle ^d	BAE Systems	Increased design-to capacities for the recovery equipment and maintenance lift to support all FCS manned and unmanned ground vehicles.
Infantry Combat Vehicle	BAE Systems	Conducted ICV mock-up ingress/egress demonstrations. Conducted critical design reviews for the gun turret drive system, multi-media slipping, off-slipping processing system and ammunition.
Medical Vehicle Evacuation/Treatment	BAE Systems	Executed MV-T Mock Up Demonstration and Evaluation Executed MV-E Pit Stop evaluation and incorporated findings in improving LLHS design, placement of medical equipment and medic workstation design.
Command and Control Vehicle ^e	General Dynamics	Maturing SIGINT integration approach. Preparing for Rooftop Deconfliction Test phase 2.
NLOS Cannon	BAE Systems	Five prototypes produced.

^a FCS Smartbook, 2008.

^b Sharafi, 2009.

^c The following risk was rated "High" in the MGV Platform Status review: "Mortar Propellant Handling and Storage."

^d It was one of five platforms deferred in 2003 and restored in July 2004.

^e The following risk was rated "High" in the MGV Platform Status review: "C2V Topdeck Design & Component Installed Performance."

and C2V variants were still maturing SIGINT (one of the primary functions of these systems) integration approaches 12 months prior to the CDR.²⁷

UAV Class I (Platoon-Level SA/SU)

Intended to weigh less than 15 pounds, the Class I UAV (Figure E.3) provided a vertical takeoff and landing capability while being teleoperated by dismounted soldiers primarily for reconnaissance, surveillance, targeting, and acquisition (RSTA).²⁸ Developed by Honeywell, which calls it the T-Hawk Micro Air Vehicle (MAV),²⁹ it has recently been used to help emergency workers obtain close-up video from Japan's dam-

²⁷ Wattam and McVeigh, 2009.

²⁸ Program Manager Future Combat Systems Unit of Action, *Army 18+1+1 White Paper*, 2004.

²⁹ Honeywell T-Hawk Micro Air Vehicle, home page, 2010.

Figure E.3
Class I UAV



RAND MG1206-E.3

aged Fukushima Daiichi nuclear facility.³⁰ In its backpackable form, it weighed 41 pounds.³¹ It uses a state-of-the-art 10hp heavy fuel engine,³² whose development was tracked as a CTE by PM FCS and further reviewed by the ASA(ALT)'s IRT.

In May 2009, this lightweight heavy-fuel engine (CTE32B) was given a TRL 5 rating by the IRT, who disagreed with the PM FCS rating of 6. An alternative engine was needed, due to previous engine development failures, and although FCS rated a fixed-wing variant of a commercial UAV engine TRL 5 in March 2009, the May 2009 IRT concluded that limited testing had occurred to justify an increased TRL 6 rating. The Class I UAV (Figure E.3) was originally³³ intended to be a part of spin-out 3. After FCS cancellation, it became a part of Early Initial Brigade Combat Team (E-IBCT) Increment-1.³⁴ In the late 2010 LUT-10 it did not show improvement in reliability over LUT-09, and user assessments deemed the Class I to have limited

³⁰ Honeywell, "Honeywell T-Hawk Aids Fukushima Daiichi Disaster Recovery," Phoenix, Ariz.

³¹ OSD briefing, "Class IV and I OSD Platform Status Review," circa February 2009. Not available to the general public.

³² OSD briefing, "Class IV and I OSD Platform Status Review," 2009.

³³ Bolton, "Memorandum for Program Manager, Future Combat Systems (Brigade Combat Team)," 2007.

³⁴ Selected Acquisition Report (SAR), "Inc 1 E-IBCT," December 31, 2009, Defense Acquisition Management Information Retrieval (DAMIR).

military utility,³⁵ being too loud for tactical surprise, too heavy and bulky for use by light infantry, and with limited endurance. The Army believes, however, that various design aspects of the Class I will provide a positive return on investment. For example, the Class I was more efficient in producing thrust than a conventional propeller and operates more efficiently at higher speeds, while enhancing safety on the ground.³⁶ The engine, meanwhile, was the first successful design of a small heavy-fuel engine for a vertical takeoff and lift UAV. Foreign military have shown interest in the Class I, with the UK ordering five units for delivery in 2010,³⁷ and Indian security forces conducting trials for counterterrorism operations in October 2010.³⁸ Honeywell claims that the T-Hawk has been used in Iraq and Afghanistan for route clearance, infantry assault, and explosive ordnance disposal missions, cumulatively logging more than 17,000 hours of flight.³⁹ Despite these impressive statistics, the FCS user community recommended to stop development and not field the Class I.⁴⁰ It is unclear if Honeywell is continuing to develop the Class I (T-Hawk MAV) or variants for other Army programs or S&T efforts.

UAV Class II (Company-Level SA/SU)

The Class II UAV (Figure E.4) was one of five platforms deferred in the 2003 FCS SDD contract for affordability reasons (along with Class III, ARV-A/R, FCS Recovery and Maintenance Vehicle (FMRV) variant of MGV, and IMS) but later brought back into the program as a result of the July 2004 restructuring.⁴¹ It was intended to be an MGV launched platform providing line-of-sight enhanced dedicated imagery and target designation during day, night, or adverse weather.⁴² It was required to have a range of 16km, loiter for two hours, and be able to be carried by two soldiers.⁴³

In July 2005, the LSI awarded a 10-month contract (between \$3 million and \$5 million) to Piasecki Aircraft Corporation for its fixed-wing Air Scout UAV (a scaled-down, unmanned version of Piasecki's Air Geep), which would be a candidate for the FCS Class II UAV concurrently with DARPA's consideration of ducted-fan technolo-

³⁵ Seller Ahern (DOT&E) and Cynthia Dion-Schwartz (DDR&E), "DAB IPR for E-IBCT Inc 1," January 12, 2011. Not available to the general public.

³⁶ PEO-I, "The FCS Return on Investment: An Acquisition Outlook," no date. Not available to the general public.

³⁷ Graham Warwick, "UK Orders T-Hawk MAVs," *Aviation Week*, January 12, 2009.

³⁸ "Trials of Honeywell T-Hawk Micro Air Vehicles to Be Conducted," *India Defence*, October 10, 2010.

³⁹ Honeywell, "Honeywell T-Hawk Aids Fukushima Daiichi Disaster Recovery."

⁴⁰ Ahern and Dion-Schwartz, 2011.

⁴¹ "FCS Acquisition Program Baseline (APB)," November 4, 2005. Not available to the general public.

⁴² Program Manager Future Combat Systems Unit of Action, *Army 18+1+1 White Paper*, 2004.

⁴³ Program Manager Future Combat Systems Unit of Action, *Army 18+1+1 White Paper*, 2004.

Figure E.4
Class II UAV



RAND MG1206-E.4

gies.⁴⁴ Piasecki was also awarded a similar contract for a Class III candidate, along with two other contractors, as discussed below. The LSI's intention was to decide in 2008 which concept would eventually be fielded.⁴⁵ In January 2007 the ASA(ALT) signed a memo to stop all development work on Class II and Class III UAV. It is unclear whether Piasecki moved beyond a paper design in this short amount of time or exactly what it delivered to FCS. Although Piasecki does have proposals to develop UAVs, they are primarily for small business innovative research (SBIR) contracts, so it does not seem that the FCS experience significantly accelerated their capabilities.

UAV Class III (Battalion-Level SA/SU)

The Class III concept was envisioned to provide the capabilities of Class I and Class II in addition to chemical, biological, radiological, nuclear (CBRN) detection, mine detection, meteorological survey, and serve as a communication relay. It would also allow NLOS platforms to deliver precision fires, while being able to take off and land without a dedicated airfield, with six hours of endurance in a 40km radius.

Similarly to the Class II, the LSI awarded three ten-month contracts to simultaneously design the Class III (Figure E.5). These were awarded to Piasecki's Air Guard, AAI Corporation's Shadow III, and Teledyne Brown Engineering's Prospector, while DARPA focused on a rotorcraft concept.⁴⁶ The Army and USMC use AAI Corpora-

⁴⁴ Joshua Kucera, "UAV Competition for Future Combat System Tightens," *Jane's Defence Weekly*, July 29, 2005.

⁴⁵ Kucera, 2005.

⁴⁶ Kucera, 2005.

Figure E.5
Class III UAV



RAND MG1206-E.5

tion's Shadow 200 (basis for its Class III concept), while allied naval forces use its Shadow 400.⁴⁷ As the Class III was also cancelled in January 2007, along with the Class II, it is questionable whether the contractors were able to move beyond paper designs and provide any useful deliverables to FCS. On the other hand, the short time allotted for design probably did not substantially increase these contractors' existing UAV capabilities either.

UAV Class IV (Brigade-Level RSTA)

The Class IV UAV (Figure E.6) was envisioned to have many of the same sensing and communication functions as the Class III UAV, but with much longer endurance and flight range. It had an objective endurance of 18–24 hours and a 75km radius of action.⁴⁸ In 2009, the system description was much more modest, with 4–7 hours of endurance (depending on payload), a risk highlighted in a platform system review along with electromagnetic environment effects.⁴⁹ Northrop Grumman's Fire Scout UAV was selected as the Class IV concept in August 2003,⁵⁰ to be eventually integrated with countermine sensors from the ASTAMIDS complementary program. The Fire Scout has been the basis for many variants across services, including the Navy and Marine Corps. The design and integration of various sensors (electro-optical, infrared,

⁴⁷ AAI Textron Systems, *Shadow® Tactical Unmanned Aircraft Systems (TUAS)*, no date.

⁴⁸ Program Manager Future Combat Systems Unit of Action, *Army 18+1+1 White Paper*, 2004.

⁴⁹ OSD briefing, "Class IV and I OSD Platform Status Review," 2009.

⁵⁰ Northrop Grumman, "MQ-8B Fire Scout Vertical Unmanned Aircraft System," no date.

Figure E.6
Class IV UAV



RAND MG1206-E.6

laser designator, and laser ranger finder) on a UAV is one output that resulted from the Class IV effort, and which did not exist before the program.⁵¹

Although the Class IV was cancelled in 2010 in favor of modifying the existing Shadow UAV (Honeywell),⁵² Northrop Grumman continues to develop the Fire Scout in addition to developing a next-generation version called the Fire-X,⁵³ which like the Class IV will carry an array of ISR sensors with an endurance of 14 hours.

Unmanned Ground Vehicle Small Unmanned Ground Vehicle (SUGV)

SUGV (Figure E.7) is a tactical mobile robot that is remotely operated to provide situational awareness in precarious urban terrain and subterranean areas, able to climb stairs, pass doorways, and traverse rubble-type obstacles. It weighs 29 pounds and can carry a payload of up to 6 pounds while being teleoperated by a single soldier using a video game controller.⁵⁴ iRobot Corporation, which has developed robots for various

⁵¹ PEO-I, "The FCS Return on Investment: An Acquisition Outlook," no date.

⁵² Daniel Wasserbly, "US Army Axes UAS and Two UGV models," *Jane's Defence Weekly*, January 15, 2010.

⁵³ Northrop Grumman, "Unmanned System," no date.

⁵⁴ iRobot product specifications, iRobot Corporation, XM1216 SUGV, no date.

Figure E.7
Small Unmanned Ground Vehicle



RAND MG1206-E.7

applications, including the well-known Roomba home vacuum cleaner, was awarded the contract in 2003 to develop the SUGV for the LSI.⁵⁵

This platform is regarded as one of the success stories of FCS, as the Army recently approved fielding of 48 SUGVs for operational use with the 3rd Brigade Combat Team in Afghanistan.⁵⁶ In the 2006 restructuring of FCS, SUGV was planned to be a part of Spin-out 3, along with Class I/IV UAV, and ARV-Assault Light.⁵⁷ However, after the cancellation of FCS and creation of the E-IBCT program, it became part of the Increment 1 E-IBCT core systems.⁵⁸ It underwent a Technology Readiness Assessment for the Milestone C review of E-IBCT.⁵⁹

iRobot has developed numerous variants and next-generation versions of the SUGV for the Army and domestic law enforcement communities, and has expanded capabilities to include IED neutralization and hazardous material identification.⁶⁰ The SUGV PDR in 2008 pointed out various technical issues, including concerns of low-temperature operation, weight, battery lifetime, communications range, and chemical

⁵⁵ B.C. Kessner, "Lockheed Martin, GD and iRobot Picked for FCS UGV Contract Negotiations," *Defense Daily*, August 8, 2003.

⁵⁶ Daniel Wasserbly, "US Army Clears SUGVs for Operational Use," *Jane's Defence Weekly*, June 22, 2011.

⁵⁷ Bolton, "Memorandum for Program Manager, Future Combat Systems (Brigade Combat Team)," 2007.

⁵⁸ Ashton Carter, "Future Combat Systems (FCS) Brigade Combat Team (BCT) Acquisition Decision Memorandum," memorandum for Secretary of the Army, June 23, 2009.

⁵⁹ Matt Donohue, Kris Gardner, and Major Scot Greig, "Future Combat Systems (FCS) Spin Out (SO) Early-Infantry Brigade Combat Team (E-IBCT) Increment 1 Milestone C Technology Readiness Assessment (TRA)," Approved by Thomas Killion, Deputy Assistant Secretary of the Army Research and Technology, December 11, 2009.

⁶⁰ iRobot, "Ground Robots—710 Warrior," no date.

detection limitations.⁶¹ In the 2010 E-IBCT LUT, SUGV was declared the most useful system, allowing operators to locate IEDs and opposing forces. However, users also reported the time to maneuver slowed operating tempo and also increased concerns about user's safety from decreased awareness during operation.

In addition to technical solutions, such operational challenges clearly require modified tactics, techniques and procedures (TTP). Additionally, the SUGV was not able to send tactical images over the network due to difficulty in setting up communications between a gateway and Network Integration Kit (NIK). These communications problems, however, are largely related to the NIK itself, which received far lower marks from users in this Limited User Test (LUT). Overall, the soldiers and leaders approved the performance, saying "they would take SUGV to war as-is."⁶² It was the only E-IBCT system to demonstrate military utility and receive a recommendation to "field and deploy now." In early 2011, the Army was planning to issue an ADM to procure 130 SUGV units in three sets during LRIP.⁶³

UGV: Multifunctional Utility/Logistics and Equipment (MULE)

The MULE (Figure E.8) is a 2.5-ton UGV that was intended to have three variants serving specific functions: Transport, Countermine, and Armed Robotic Vehicle-Assault-Light (ARV-A-L).⁶⁴ Each shared a common chassis and Autonomous Navigation System (ANS). The countermine variant would host Ground Standoff Mine Detection System (GSTAMIDS), an FCS complementary system, to perform mine detection with Ground Penetrating Radar⁶⁵ along with lane marking and clearing for MGVs that would follow behind.

The countermine capabilities demonstrated by the MULE prompted recommendations to restore funding for GSTAMIDS in 2009, which never occurred. The Transport variant demonstrated ANS integration and dash speeds of 0–50 kph under 12 seconds, in addition to mobility on a variety of terrain: 35+ kph off road, 55 kph on concrete.⁶⁶ Developed by Lockheed Martin, the MULE variants completed PDR in 2008 with an Interim Design Review scheduled for later that year.⁶⁷ In January 2009, the MULE management was briefed on the Highly Accelerated Life Testing and

⁶¹ OSD briefing, "SUGV Quad FCS Platform Status Review," circa February 2009. Not available to the general public.

⁶² Director, Operational Test and Evaluation Command, Deputy Director, Land Expeditionary Warfare, "E-IBCT LUT 10 Operational Assessment," December 2, 2010.

⁶³ Ahern and Dion-Schwartz, 2011.

⁶⁴ Program Manager Future Combat Systems Unit of Action, *Army 18+1+1 White Paper*, 2004.

⁶⁵ OSD briefing, "UGV Platform Status Review" circa February 2009. Not available to the general public.

⁶⁶ OSD briefing, "UGV Platform Status Review," 2009.

⁶⁷ Lockheed Martin, "Lockheed Martin MULE Program Completes Key Review, Begins Work on Final System Design," Dallas, Tex.: February 27, 2008.

Figure E.8
MULE



RAND MG1206-E.8

Stress Screening (HALT/HESS) process and their advantages; however, the MULE test schedule at the time did not allow sufficient margin to include Corrective Action Periods. A variety of subcomponents of the MULE were considered as HALT candidates. The Transport and Countermine variants of the MULE were cancelled in January 2010, with the ARV-A-L variant thought to continue development;⁶⁸ however, it is unclear if Lockheed Martin is still pursuing this variant, although it does appear to be a brigade combat team modernization (BCTM) capability.⁶⁹

Lockheed Martin (Missiles and Fire Control division) may have leveraged its experience from the MULE-Transport to create the Squad Mission Support System (SMSS) UGV. SMSS is providing a portable power solution to the Army, complementing the Net-Warrior Soldier technology package.⁷⁰ This UGV has participated in various user tests since 2008, and most recently the Army Expeditionary Warrior Experiment, Spiral G in 2011.⁷¹ SMSS is anticipated to perform in the Military Utility Assessment in Afghanistan.⁷²

⁶⁸ Wasserbly, "US Army Axes UAS and Two UGV models," 2010.

⁶⁹ Army Brigade Combat Team Modernization, "XM1219 Armed Robotic Vehicle-Assault-Light (ARV-A-L)," no date.

⁷⁰ Lockheed Martin, "SMSS," no date.

⁷¹ Lockheed Martin, no date.

⁷² Lockheed Martin, no date.

GSTAMIDS, a CP that enabled the Advanced Countermine detection and neutralization (CTE30A/B), continues to be developed by BAE Systems.⁷³ During the FCS program, it would provide countermine capabilities when integrated with the FCS MULE. Integration of complementary program critical technologies will continue to challenge future acquisition efforts, and the GSTAMIDS-FCS interaction may be worth documenting from a technology development standpoint. Also, it is unclear whether there was any integration technology developed to serve as an intermediary between the GSTAMIDS system and the FCS MULE.

UGV: Armed Robotic Vehicle (ARV)

The ARV (Figure E.9) was a UGV developed in two variants sharing a common chassis: (1) Assault and (2) Reconnaissance, Surveillance, and Target Acquisition (RSTA).⁷⁴ In 2003 both ARV-A and ARV-R were deferred due to affordability reasons but later brought back into the program as a result of the July 2004 restructuring.⁷⁵ During the 2006 restructuring, both variants of the ARV were removed⁷⁶ and the ORD requirements for these systems were required to be changed and treated as “objective requirements.” Both ARV were “returned to Tech Base for further technology maturation.”⁷⁷ This new S&T effort was titled Robotic Vehicle Control Architecture (RVCA) and was staffed through the Tank Automotive Research, Development and Engineering Center (TARDEC) and developed by BAE and General Dynamics Robotics System.⁷⁸ One of the results from this effort is the Autonomous Platform Demonstrator (APD), a 9.6-ton, six-wheeled hybrid electric vehicle, capable of hosting an Autonomous Navigation System (ANS). In 2008, the ANS underwent an experiment at White Sands Missile Range (WSMR) to demonstrate teleoperation and did so at 55 kph, the desired goal, while also demonstrating “follower mode” at a variety of speeds and distances.⁷⁹ In 2010 it was undergoing testing for high-speed (50 mph) autonomous maneuverabil-

⁷³ Weapon Systems 2011; United States Army, “Countermine,” no date.

⁷⁴ Program Manager Future Combat Systems Unit of Action, *Army 18+1+1 White Paper*, 2004.

⁷⁵ “FCS Acquisition Program Baseline (APB),” November 4, 2005. Not available to the general public.

⁷⁶ Bolton, “Memorandum for Program Manager, Future Combat Systems (Brigade Combat Team),” 2007.

⁷⁷ Selected Acquisition Report (SAR), “FCS,” December 31, 2006, Defense Acquisition Management Information Retrieval (DAMIR).

⁷⁸ Philip Frederick (U.S. Army TARDEC), Robert Kania, Wade Bantz, Don Hagner, Joe Arfa, and Alberto Lacaze, “Near Autonomous Unmanned System (NAUS) Army Technology Objective (ATO) Program Results,” Proceedings of the 2009 Ground Vehicle Systems Engineering and Technology Symposium (GVSETS). See also Chris Mocnik, “Robotic Vehicle Control Architecture for FCS Program Overview,” Vehicle Electronics and Architecture Office, U.S. Army RDECOM-TARDEC, January 15, 2009. Presented at AUVSI’s Unmanned Systems Program Review 2009, February 3–5, 2009, The Mandarin Oriental Hotel, Washington, D.C.

⁷⁹ “ANS Robotics Convoy Experiment (RCX), Phase IIA,” no date. Not available to the general public.

Figure E.9
Illustration of Proposed Armed Robotic Vehicle



RAND MG1206-E.9

ity and low-speed extreme-terrain abilities.⁸⁰ Although ANS was cancelled in August 2011, the contractor, General Dynamics Robotic Systems, has lobbied Army acquisition to reconsider a “red team” analysis, which supported the decision and has further argued the continuing need for this robotic capability to meet requirements such as counter IED.⁸¹ Another related TARDEC ATO is the Near-Autonomous Unmanned System (NAUS), which was used to reduce FCS risk by maturing robotics technology and may have developed (GDRS and BAE) the ART/ATO vehicle.⁸²

Unattended Ground Sensors (UGS)

Textron Defense Systems developed the Tactical and Urban variants of the UGS. The sensors included various modalities: acoustic, electro-optics/IR, radiation, nuclear, passive IR, and seismic.⁸³ Despite the FCS cancellation, these sensors became a part of the E-IBCT program⁸⁴ in December 2009. Textron Defense Systems announced that UGS entered LRIP after a positive Milestone C review process, and scheduled deliv-

⁸⁰ Kris Osborn and Andrew Kerbrat, “Army Testing Rugged, Autonomous Robot Vehicle,” U.S. Army home page, June 2, 2010.

⁸¹ “House Lawmaker Wants to Save Army’s Autonomous Navigation System,” *Inside the Army*, August 15, 2011.

⁸² General Dynamics Robotic Systems, “Near Autonomous Unmanned Systems (NAUS)-Advanced Technology Objective (NAUS-ATO),” no date.

⁸³ Textron Defense Systems, “Unattended Ground Sensors—Brigade Combat Team Modernization,” no date.

⁸⁴ Selected Acquisition Report (SAR), “Inc 1 E-IBCT,” December 31, 2009, Defense Acquisition Management Information Retrieval (DAMIR).

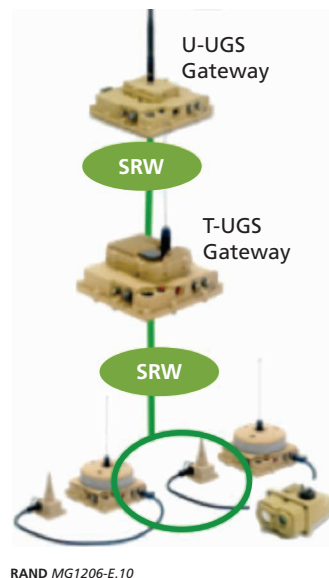
ery of T/U-UGS to the 3rd Brigade Combat Team for initial operational test and evaluation.⁸⁵

At present, Textron has developed a next-generation UGS solution to classify and track personnel and vehicles for various applications, including border security, critical infrastructure protection, and force protection (Figure E.10). It is highly likely that the development of this next-generation UGS, the MicroObserver,⁸⁶ benefited from its FCS predecessors. Presently, the MicroObserver does not seem to be part of any Army modernization plans. The diversification in applications of this next-generation sensor may have been the result of negative user assessment of the T/U-UGS in E-IBCT operational testing, which concluded⁸⁷ that these sensors “provided the unit little useful tactical intelligence,” and recommended to stop development and not field.

Non Line of Sight Launch System (NLOS-LS)

Informally known as “missiles in a box,” NLOS-LS consists of a Container Launch Unit (C/LU) and 15 vertical launch missiles. The C/LU has fire-control electronics and communications hardware for remote operation, and can house 15 missiles, of

Figure E.10
Unattended Ground Sensors



⁸⁵ Textron, “Textron Defense Systems’ Unattended Ground Sensors Enter Low-Rate Initial Production After Positive Milestone C Decision,” Wilmington, Mass., May 25, 2010.

⁸⁶ Textron Defense Systems, “MicroObserver® Unattended Ground Sensors,” no date.

⁸⁷ Director Operational Test and Evaluation Command, “E-IBCT LUT 10 Operational Assessment,” 2010.

which there were initially two types: Precision Attack Missiles (PAM) and Loitering Attack Missiles (LAM) (Figure E.11). PAM supports laser-designation and autonomous operation with an ability to transfer imagery prior to impact. LAM was intended to provide RSTA capabilities for high-value targeting and battle damage assessment (BDA) while also serving as an airborne radio relay for other missiles.⁸⁸ RDECOM M&S facilities participated in a simulation experiment⁸⁹ for FCS networked fires in 2004 producing various observations on the utility and network performance impacts on and of NLOS-LS. As the network concept and NLOS-LS were still maturing, it is difficult to judge the accuracy of such simulations, but general observations from the effort suggest the LAM provided little BDA capability and a “stop-gap measure” for reconnaissance and surveillance.⁹⁰ Netfires LLC, a joint venture between Lockheed Martin and Raytheon, developed the NLOS-LS platform as a core system to the FCS program but under a separate SDD contract.⁹¹ NLOS-LS was the result of an earlier DARPA–Army S&T technology development contract awarded to both Raytheon and Lockheed Martin as part of the Netfires program.⁹²

In 2006, the Navy awarded Netfires LLC a contract to develop a NLOS-LS variant for the Littoral Combat Ship.⁹³ NLOS-LS completed a PDR in December 2005 and a CDR a year later.⁹⁴ As part of Spin-out 1, NLOS-LS was required to meet the following Milestone C exit criteria:⁹⁵ defeat stationary targets at range and successfully send a call for fire mission to the C/LU. Although the 2006 ORD⁹⁶ states that “NLOS-LS must have loitering munitions,” it seems that LAM was left out of the FCS 2006 SAR, leaving only the C/LU and PAM.⁹⁷ After the cancella-

⁸⁸ Program Manager Future Combat Systems Unit of Action, *Army 18+1+1 White Paper*, 2004.

⁸⁹ Gregory Tackett and Timothy McKelvy, “RDE Command First Application (1st App) Simulation Experiment for Future Combat Systems (FCS) Networked Fires,” Technical Report AMR-SS-04-14, System Simulation and Development Directorate Aviation and Missile Research, Development, and Engineering Center, June 2004.

⁹⁰ Tackett and McKelvy, 2004.

⁹¹ PM FCS BCT, Submitted by MG Charles Cartwright, “Acquisition Strategy Report, Revision 2, Future Combat Systems,” Sec. 4.6.3, 2008. Not available to the general public.

⁹² “Non-Line-of-Sight Launch System (NLOS-LS),” *Global Security*.

⁹³ “US Navy Orders NLOS-LS for Littoral Combat Ships,” *Jane’s Missiles and Rockets*, October 11, 2006.

⁹⁴ OSD briefing, “NLOS-LS Platform Status Review,” 2009.

⁹⁵ Kenneth Krieg, “FCS Defense Acquisition Board Acquisition Decision Memorandum,” memorandum to Secretaries of the Military Department, Vice Chairman, Joint Chiefs of Staff Assistant Secretary of Defense Chairman, Cost Analysis Improvement Group, June 6, 2006 ADM (signed by Kreig).

⁹⁶ [ORD 3435, 2.0.4.1.2] in UAMBL, “Operational Requirements Document (ORD) for the Future Combat Systems: 27 Apr 06 JROC Approved/Validated Change 2,” Fort Knox, Ky.: UAMBL, April 27, 2006. Not available to the general public.

⁹⁷ Selected Acquisition Report (SAR), “FCS,” 2006. See also “USA’s \$160+ Billion Future Combat Systems Restructured,” *Defense Industry Daily*, February 9, 2007.

Figure E.11
NLOS-LS Container Launch Unit (C/LU) Shown
Transported on a Truck and Subsequently
Firing Its Precision Attack Munition (PAM)



RAND MG1206-E.11

tion of FCS, NLOS-LS became officially⁹⁸ part of the E-IBCT Increment 1 program in 2009. A “flight LUT” of the PAM conducted in February 2010, resulted in only two hits and four misses. In addition to performance concerns, a portfolio analysis of precision weapons conducted by the Vice Chief of Staff of the Army found that the system lacked value, prompting the Army to urge cancellation of the program in April that year.⁹⁹ In May 2010, the Army was granted approval to cancel NLOS-LS, along with HASC recommendation that \$75 million in R&D funds be transferred to the Navy,¹⁰⁰ presumably to continue development of NLOS-LS for its Littoral Combat Ship. The Army’s decision to evaluate the cost-benefit tradeoff of a \$300,000 system, in light of other similar capabilities, was applauded by the USD(AT&L).¹⁰¹ It

⁹⁸ Selected Acquisition Report (SAR), “Inc 1 E-IBCT,” 2009.

⁹⁹ “US Army Urges NLOS-LS Cancellation,” *Jane’s Defence Weekly*, April 26, 2010.

¹⁰⁰ “Pentagon Agrees to Army’s NLOS-LS Cancellation,” *Jane’s Defence Weekly*, May 14, 2010.

¹⁰¹ Ashton B. Carter, Office of the Under Secretary of Defense, Acquisition, Technology, and Logistics, “Better Buying Power: Guidance for Obtaining Greater Efficiency and Productivity in Defense Spending,” memorandum for acquisition professionals, Washington, D.C., September 14, 2010.

is unclear if the Navy's LCS program will pursue NLOS-LS or some other surface-to-air missile, as it is reviewing 50 different options.¹⁰²

Intelligent Munitions System (IMS)

IMS is a remote operated, hand placed anti-vehicle munition, resembling a landmine but able to deliver both lethal and nonlethal effects with an on/off capability allowing it to be a recoverable alternative to traditional landmines,¹⁰³ and designed for interoperability with the FCS network (Figure E.12).¹⁰⁴ Textron Defense Systems developed IMS, later renamed Scorpion, as the networked munitions capability for FCS. It was awarded a \$115 million contract for the design and development in July 2006.¹⁰⁵ In order to comply with the U.S. landmine policy directive of 2004, DoD developed two Networked Munitions systems to replace persistent anti-personnel and anti-vehicle landmines, the Spider and Scorpion (formerly IMS) respectively.¹⁰⁶ In May 2006, a

Figure E.12
Intelligent Munition System



RAND MG1206-E.12

¹⁰²Ronald O'Rourke, "Navy Littoral Combat Ship Program: Background, Issues, and Options for Congress," Congressional Research Service, CRS RL33741, April 29, 2011.

¹⁰³Program Manager Future Combat Systems Unit of Action, *Army 18+1+1 White Paper*, 2004.

¹⁰⁴Textron Systems, "Delivering Confidence, Scorpion: More Power, More Protection," Wilmington, Mass., 2010.

¹⁰⁵"Intelligent Munitions System (IMS)," *Defense Update: International Online Defense Magazine*, No. 1, 2006.

¹⁰⁶*Army Modernization Strategy*, Department of the Army, Office of the Deputy Chief of Staff for Programs, 2010.

DAB review resulted in an approval of the FCS SO1 Milestone C exit criteria,¹⁰⁷ which included that the IMS “autonomously engage targets with lethal effects munitions and achieve kills.” As part of the 2006 restructuring, IMS was officially deleted from the FCS SDD contract in a January 11, 2007 memo¹⁰⁸ signed by the ASA(ALT), which also deleted it as a Spin-out 1 system. The Army has stated that decrements in funding and their analysis of requirements indicated it was no longer achievable with available funding, and that the system that was achievable was not required. The 2007 memo states that the “ORD requirement for these systems will be changed and treated as an ‘objective requirement,’” leading the 2008 ASR to recommend retaining IMS as a complementary program.¹⁰⁹

The Project Manager for Close Combat Systems (PM-CCS) continued to manage the development of IMS,¹¹⁰ renamed Scorpion, but it may also be facing termination.¹¹¹ However, a 2011 R-2 budget summary shows funding estimates for Scorpion through 2015.¹¹² The anti-personnel landmine alternative, Spider, entered LRIP in March 2011 with a \$34 million firm-fixed-price contract awarded to Alliant Techsystems and Textron Defense Systems by Picatinny Arsenal.¹¹³

Network Software and Hardware

The FCS network employed JTRS and WIN-T hardware and a variety of software to control these software-defined radios for network operations. In addition, software applications for battle command and logistics support were hosted on the network through the SoSCOE (System of Systems Common Operating Environment) running on the Integrated Computer System (ICS). A DoD instruction has established policies for ACAT 1–4 programs to reduce the development of new waveforms and modifica-

¹⁰⁷ Kreig, 2006.

¹⁰⁸ Bolton, “Memorandum for Program Manager, Future Combat Systems (Brigade Combat Team),” 2007.

¹⁰⁹ PM FCS BCT, Submitted by MG Charles Cartwright, “Acquisition Strategy Report, Revision 2, Future Combat Systems,” Sec. 4.6.3, 2008. Not available to the general public.

¹¹⁰ Project Manager Close Combat Systems, “Product Manager Intelligent Munitions System (IMS),” no date.

¹¹¹ Email correspondence:

In addition, have also been working with the Intelligent Munitions System (IMS - Scorpion) Program for the last year and a half, which was also recommended or termination by the AAE (determination to pursue more affordable Anti-vehicle solution), and subsequently terminated by the DAE, and is in the process of closing-out.

¹¹² RDT&E Budget Item Justification for Army, PB 2011, p. 1547:

Project 016, Close Combat Capabilities Engineering Development, provides for the development of the anti-vehicle mine replacement, Scorpion (previously the Intelligent Munitions System (IMS)) supports the current force in accordance with the landmine policy.

¹¹³ Department of Defense, Office of the Assistant Secretary of Defense (Public Affairs), “Contracts,” No. 224-11, March 21, 2011.

tions to existing ones to reduce network complexity.¹¹⁴ Three of the FCS waveforms, HNW, WNW, and SRW, are included as net-centric and IP-capable, another policy focus of the instruction.¹¹⁵ It is then pertinent to salvage any FCS technologies associated with these waveforms such as MANET protocols, QoS algorithms, or cross-domain guarding solutions, all CTEs for FCS, and ensure that all possible value has been realized. Without further investigation as to the end-state status of these technologies, potentially redundant efforts may be expended in developing routing, application prioritization, and security for future Army networks.

Network Integration Kit (NIK)

The NIK was designed to provide FCS-like mobile networking and computing capabilities to the current force through the E-IBCT limited capabilities package. It consists of the following components: ICS with a cross-domain guarding solution to allow unsecured sensor data into classified enclaves of the network; Incremental Battle Command Extension (IBEX) consisting of chat, file transfer, and map-based collaboration tools; Force XXI Battle Command Brigade and Below (FBCB2) Joint Capabilities Release (JCR) display interface to view blue/red battle space objects, network status and performance, view sensory image, and chat with both NIK and non-NIK equipped platforms; JTRS Ground Mobile Radio (GMR) and Network Management System (NMS) to provide management of voice and data communications.¹¹⁶

The JTRS GMR will support new waveforms enabling greater information capacity and data rates, such as Solider Radio Waveform (SRW) and Wideband Networking Waveform (WNW). The NIK must also integrate legacy waveforms, such as SINGCARS, used for voice applications.

The DAB IPR for E-IBCT Increment 1 highlighted several issues with the NIK through LUT and a DDR&E Network Assessment.¹¹⁷ The LUT concluded limited utility for the NIK as a sensor relay, poor SINGCARS voice quality, long NIK startup times, and information assurance vulnerabilities. The NIK fell 33 hours short of its Mean Time Between System Abort reliability requirement of 112 hours. Although the GMR has Network Management System (NMS) software, the LUT also reported a lack of network management tools at the brigade and battalion level. Another problem highlighted was the low message completion rate of sensor images transferred with WNW, ranging from 42 to 60 percent success, smaller than required. Performance in the LUT terrain environment may not represent a worst-case when compared to theatre terrain, which was analyzed to likely further degrade performance. Despite these

¹¹⁴ Department of Defense, "Wireless Communications Waveform Development and Management," Instruction No. 4630.09, November 3, 2008.

¹¹⁵ Instruction No. 4630.09, 2008.

¹¹⁶ U.S. Army, "The Network and the Network Integration Kit (NIK)," March 9, 2011.

¹¹⁷ Ahern and Dion-Schwartz, 2011.

concerns, the user community is recommending to continue developing the NIK as integral component of the network, reducing both the start-up times and improving SINGCARS integration. A 2011 combined LUT is scheduled for the July time frame to address these problems in addition to the WNW message completion rates and information assurance issues.

SoSCOE

Developed by Boeing, the System of Systems Common Operating Environment is built on top of a COTS Linux operating system. It provides various services which isolate applications, such as battle command or logistics software, from the details of interacting with the FCS network, providing information assurance and, more generally, low-level or common services that are not application specific. The SoSCOE toolkit includes developer tools, documentation, and runtime software.¹¹⁸ SoSCOE comes in three editions, Micro, Real Time, and Standard with increasing complexity and size to provide scalability across platforms with varied computing resources. Its development was phased in four major builds, with greater functionality added incrementally, and software releases every three months.¹¹⁹ To lower the cost of development and maintenance, SoSCOE utilizes open-source, COTS, and GOTS software packages; in build two it had 53 open-source and 14 COTS/GOTS packages. It is forecasted to have ~20 million effective software lines of code in its final form.¹²⁰

To obtain the greatest use and reuse of software created during FCS, the Army and Boeing have signed a Statement of Work to deliver various software products from the contractor to the Army beginning after the conclusion of FY10 LUT.¹²¹ It specifies that the Army take possession of all source code (with some exceptions), model files, test source code and test cases, support files, databases, and data sets, with prioritization placed on those materials required to independently rebuild and test the software deliveries.¹²² With the goal of supporting a successful independent Army capability to perform software development and integration, the SOW specifies various software component and software development products (e.g., help ticket databases) that must be transferred to the Army along with technical engineering support until August 31, 2011, to accompany the SoSCOE v10.8 update.

Other efforts to compile and archive software, which may have overlap with the above SOW, have been undertaken by the Software Engineering Directorate of PEO-I, which is attempting to stand up and maintain a software repository at Red-

¹¹⁸ "PM FCS (BCT) ESLOC History," OSD overview of SoSCOE, March 2009. Not available to the general public.

¹¹⁹ "PM FCS (BCT) ESLOC History," 2009.

¹²⁰ "PM FCS (BCT) ESLOC History," 2009.

¹²¹ W56HZV-05-C-0724 Modification P00318, Data Product Detail Instructions, p. 121.

¹²² W56HZV-05-C-0724.

stone.¹²³ Although a potentially time-intensive task, given its complicated structure, it may be worthwhile to salvage components of SoSCOE, whose source code is currently housed by Aviation and Missile Research, Development, and Engineering Center (AMRDEC).¹²⁴

Logistics Software

Logistics software applications were also highlighted as demonstrating value during the program. Three applications that are built upon SoSCOE services include:¹²⁵

- Platform Soldier Mission Readiness System (PSMRS): a single software application that provides condition based diagnostics, prognostics, and readiness status for all FCS systems.
- Logistics Decision Support Services (LDSS): provides services to plan and monitor sustainment activities as well as to aggregate and report readiness and a logistics common operating picture via the FCS battle command network.
- Logistics Data Management Services (LDMS): creates a software portal used by logisticians/supply teams to access and manage FCS logistics data (enabling Performance Based Logistics).

All three of the above applications are being managed by PEO-I for BCT modernization.¹²⁶

3CE/AAMSES

The Cross-Command Collaborative Effort (3CE) created a network to share M&S capabilities, assumptions, and results across TRADOC, ATEC, RDECOM, and the PM and LSI.¹²⁷ Given the significance of M&S for FCS development, and the horizontal integration of various capabilities across the stakeholder organizations, 3CE is an output that may be worth leveraging for future SoS acquisitions depending on its end-state and required investment for sustainment and upgrades. With 3CE in place, the four organizations agreed to use a common set of M&S tools for FCS, with One Semi-Automated Forces (OneSAF) being the primary force-on-force simulator, and the Communications Effects Server (CES) as the primary communications M&S tool. 3CE is both a process and technical infrastructure, and in its current incarnation, is

¹²³Interview data.

¹²⁴Interview data.

¹²⁵Soo Yoon, "Net Centric Operations Logistics—FCS," 11th Annual Systems Engineering Conference, NDIA, October 20–23, 2008.

¹²⁶Hosmer, 2011.

¹²⁷"Cross-Command Collaboration Effort (3CE)," 2008.

known as AAMSES,¹²⁸ although it is unclear how the Army is using it at the present time.

There are many technologies that resulted from FCS, some of which may be worth leveraging for future acquisition efforts. However, as we have emphasized, presently there is no coherent Army-wide effort to determine the present “owner(s)” and the future value of these technologies. In a following section, we examine whether a “Book of Knowledge,” such as the one created for the MGCV, is a useful device to capture technical lessons and outputs on a platform-by-platform basis. Although such a platform perspective will capture a variety of technologies, it should be complemented by an account of present ownership and future value of those technologies that implemented the 44 CTEs which remained through the duration of the program.

E-IBCT

After the cancellation of FCS in April 2009, a new program known as E-IBCT was started.¹²⁹ FFID assumed responsibility for evaluation of the spin-out capability packages while becoming the Army’s central network integration organization, which required a full BCT; thus the 2nd Brigade, 1st Armored Division, took over the AETF mission.¹³⁰ E-IBCT Increment 1 package, managed by PEO-I, included four main systems from the original 18 in addition to a Network Integration Kit (NIK). These four systems previously developed in FCS include Class I UAV, SUGV, NLOS-LS, and Tactical and Urban Ground Sensors and were selected for early fielding because of their “technological readiness,” and as they begin to “address these needs identified by the Combatant Commanders in theater.”¹³¹

In August 2009, AETF began LUT on initial spin-out technologies from FCS which were then part of the E-IBCT program, Due to poor test results and affordability issues, the Army decided to cancel NLOS-LS in April 2010.¹³² In later testing

¹²⁸Exhibit R-2A, RDT&E Project Justification: PB 2011 Army, February 2010, pp. 870–872.

Transitions from funding of the Cross Command Collaboration Effort (3CE) to establish the Army Acquisition M&S Enterprise Solution (AAMSES) to support the new Army Modernization strategy. AAMSES will provide the required capability to transition overarching M&S development and integration responsibility from the contractor to the Government, and provide for a sustainable simulation environment to allow soldiers to execute and evaluate modernization capabilities in an operationally relevant and realistic synthetic environment.

¹²⁹“FCS BCT Acquisition Decision Memo,” Memorandum for Secretary of the Army, June 23, 2009, signed by Ashton B. Carter, USD(AT&L). “The SO E-IBCT acquisition is designated a pre-MDAP. It will acquire FCS-developed products for seven Infantry BCTs and will start as scheduled with a Milestone C decision in first quarter FY 2010.”

¹³⁰“FCS BCT Acquisition Decision Memo,” 2009.

¹³¹Capability Production Document (CPD) for FCS Spin Out (SO) Early Infantry Brigade Combat Team (E-IBCT) Increment: 1. Prepared for Milestone C, Final version, April 20, 2009. Not available to the general public.

¹³²Kate Brannen, “Army Asks to Cancel NLOS-LS,” *Army Times*, April 23, 2010.

the Class I UAV was found to be too loud, heavy, and unreliable, while the T/U-UGS provided little useful tactical intelligence.¹³³ The NIK was also deemed to have limited military utility, unable to serve its primary function as a sensor relay, vulnerable to CNO, and failing to meet its 112-hour mean time between system abort (MTBSA) requirement. One especially troubling aspect of the MANET was that the mobility of some radios would cause the entire network to crash.¹³⁴ Furthermore, only a 29-node static network was successfully demonstrated, not yet sufficient to prove MANET scalability to an 81-node brigade-sized network.¹³⁵ Only the SUGV demonstrated military utility in a number of tactical scenarios.

MGV Book of Knowledge and Knowledge Captured for Other Systems May Provide Some Future Guidance

There are indications that the upcoming GCV program will take a more conservative approach to technology development, first determining the art of the possible and practical in order to evaluate technical viability before integrating the technologies into the brigade.¹³⁶ As we have seen with various examples in FCS, including MANET protocols, APS, and high-density battery power technologies, determining the state of the art is a crucial first step to realistically gauge the challenge of developing any technology. One way to harvest the technical lessons from FCS is to follow the example of the MGV Book of Knowledge, which was created to guide potential contractors for the GCV program.

The MGV BoK is a repository of over 450 documents¹³⁷ that were selected from graded¹³⁸ MGV PDR documents. The selection process for these documents was manually intensive and required insight to determine whether the information would be relevant and useful for the GCV program.¹³⁹ It is intended to provide the industry awareness of MGV design technologies so that they may potentially leverage the development experience and maturity of MGV from the software, hardware, or system design perspective. Although not a replacement for the final GCV RFP, which contains all the requirements, it may provide some technological solutions still relevant for GCV designs. The government's intent by producing this BoK for the contractors

¹³³Ahern and Dion-Schwartz, 2011.

¹³⁴Ahern and Dion-Schwartz, 2011.

¹³⁵Ahern and Dion-Schwartz, 2011.

¹³⁶Interview data.

¹³⁷Interview data. July 25, 2011: repository is not part of ACE, since Boeing is a potential bidder for GCV.

¹³⁸Interview data.

¹³⁹Interview data.

bidding on the GCV program is to help transition ideas, designs, and knowledge from the FCS effort into the GCV effort and thereby reap some benefits from the efforts expended during the FCS program.

The BoK emphasizes that its source documents have demonstrated compliance and readiness for a formal PDR, consisting of a Horizontal Integration Review (HIR), Common Integration Review (CIR), Restricted Integration Review (RIR), and Mission Module Integration Reviews (MMIR).¹⁴⁰ Without such a demonstrated breadth of PDR preparation, it will be difficult to convince potential users of the reliability of the information. The HIR assesses the architectural elements, operational concepts, and functionality of the entire family of vehicles (all MGCV variants). The CIR assesses the common elements and fundamental platform of all variants. The MMIR assesses integrated vehicle PIDS, mission module unique CIDS, and the integration of HIR/CIR with variant-unique system-level performance.

Since the primary intent of the BoK is to serve as a repository of relevant technical information, the design goals of the MGCV are highlighted as being balanced amongst the multitude of requirements: force protection/survivability, lethality, supportability, commonality, affordability, deployability, and ability to accommodate advanced networking. Although there were eight variants of the MGCV, each was based on a common chassis that provided various survivability, mobility/transportability, and sustainment technologies. The technologies that are highlighted in the BoK executive outbrief form a representative list,¹⁴¹ which may be most relevant to GCV (Table E.4).

An exhaustive list would require parsing the entire repository of 450 documents,¹⁴² and such an effort would presuppose a greater relevance to GCV than should be rationally expected. Another potential downside to creating such an exhaustive list would be to hamper the creativity of new technological solutions for the GCV.

The Infantry Carrier Vehicle (ICV) variant of the MGCV is singled out and further detailed in the executive outbrief because the GCV will serve a similar function (Figure E.13).¹⁴³ The ICV would have held a nine-man infantry squad while being highly lethal, survivable, and networked. It was based on a “soldier-centric” design, with features such as a remotely operated turret to maximize soldier protection, and an environmentally controlled overpressure compartment. The ICV was being developed by United Defense, now BAE, and was cancelled in April 2009 along with the other MGCV variants (the NLOS-C was cancelled later in December 2009). Some aspects of the ICV even underwent a critical design review, namely the gun-turret drive system, multi-media slip ring, off slip ring processing system, and ammunition handling sys-

¹⁴⁰Ernie Wattam and Colonel McVeigh, MGCV IPT Directors, “MGCV Preliminary Design Review—Executive Outbrief,” February 11, 2009. Not available to the general public.

¹⁴¹Interview data.

¹⁴²Interview data.

¹⁴³Interview data.

Table E.4
Example Technologies Represented in the MGCV Book of Knowledge

Category	Technology
Armor	Armor Recipe Evolution of MGCV Design
Turret	Multi-Media Slip Ring (MMSR)
	Off Slip Ring Processor (OSRP)
Gun Turret Drive System (GTDS)	Turret Drive Motor
Fires	30 mm Air-Burst Munition (ABM)
	Ammunition Handling System (AHS)
	Remote Operating Kit (ROK) for M240
Sights	Medium Range Electro-Optic (MREO) Sensor
	AiTR
Interior	Environmental Control System (ECS)
Hit Avoidance System (HAS)	Short Range Countermeasure (SRCM)
	Long Range Countermeasure (LRCM)
	Multi-Function Radio Frequency (MFRF) RADAR
	Laser Warning Receiver
	Threat Warning Sensor
	Multi-Function Countermeasure (MFCM)
	Hit Avoidance Countermeasure Controller (HACC)
CORE-V developed Controllers	Servo Motor Controllers (SMCs)
	Branch Load Controllers (BLCs)
	Remote Interface Units (RIUs)
Suspension	Semi-Active Hydro-Pneumatic Suspension Units
Power	Lithium-Ion Batteries

tem.¹⁴⁴ Some of the lethality features include 30 mm selectable multi-purpose (air-burst, point detonate with/without delay) armor piercing ammunition, 1.5 km range, and 120–200 rounds per minute.

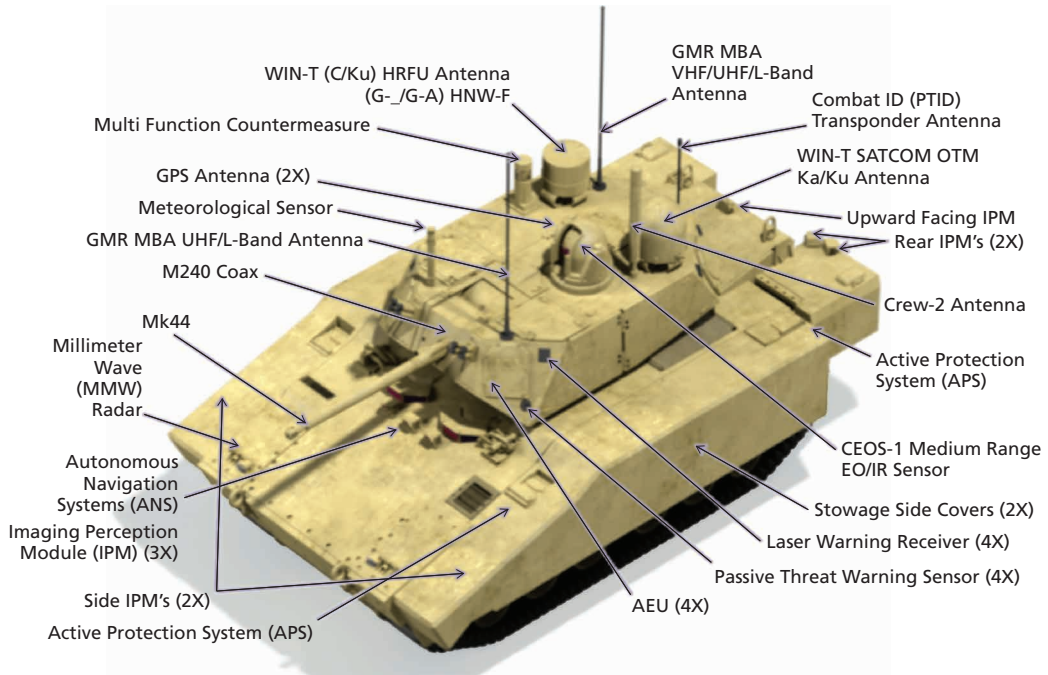
Is There Value in Creating a BoK for Other FCS Platforms?

Besides the eight MGCV variants, there were ten unmanned platforms comprising the FCS family of systems. In order to determine whether there is any value in creating a BoK for these unmanned platforms, the following questions must be addressed:

- Does the Army have any interest in further pursuing the platform?
- Is the technical documentation pertaining to the platform reliable?
 - Was it graded either in preparation for or as part of a formalized design review?
- Where does the source information reside presently?

¹⁴⁴Sharafi, 2009.

Figure E.13
XM1206 Infantry Combat Vehicle (ICV) Is the MGCV Variant That Will Most Closely Resemble the GCV



RAND MG1206-E.13

- Does the Army have rights to further disseminate this information as part of an open and competitive bid RFP?

The first question can be answered by considering the status of the platforms at the end of the program and examining any interest or disinterest expressed in pursuing such a capability further. Of the platforms for which there is a future need, there are basically two categories: those continuing to be developed by the same contractor in other programs, perhaps with some variation; and those without a follow-on effort. For the first category, ensuring that the contractor has data rights from FCS may be more valuable than expending resources to create a BoK. However, for the second category of platforms, creating a BoK-like repository would provide a tangible return on investment and perhaps instill a program management discipline of capturing technical lessons, even from prematurely cancelled programs. If a platform does fall into the second category, but the Army's future investment plans for that capability are unknown, further cost-benefit analysis will be required to justify the investment of generating a BoK, which nonetheless would capture technical lessons. The need for documenting technical experiences by those who will use it, such as Army program officials, is sound

business practice¹⁴⁵ and should be formalized into a process, which could be planned at the start of a SDD effort and followed throughout to decrease the burden of creating a repository at the very end of a program.

With regard to reliability of the source information that may be used to create a BoK for any of the platforms, we recommend that the ASA(ALT) consider reexamining the quality of any system-level PDR that the platform may have undergone. This will require personnel who were involved in the generation and perhaps grading of these documents, and is thus a nontrivial investment of time and resources.

Table E.5 summarizes our subsequent discussion of the various platforms and our recommendations for creating a BoK following the reasoning outlined above.

Of the above unmanned platforms, the Class II and Class III UAV had the shortest design life spans, with ten-month contracts awarded in 2005¹⁴⁶ and cancelled soon after as part of the 2006 restructuring.¹⁴⁷ Class II and III served the company and battalion level for greater situational awareness and understanding (SA/SU). Furthermore, given the short time period of the design effort for each, the likelihood of technical documentation being significant enough for future design efforts is relatively low. Although the Army's 2010–2035 roadmap for UAS has reorganized the need for a different size/range of UAS from classes to groups, there is still a need for

Table E.5
Summary of Recommendations to Capture Knowledge from FCS Platform Development Experience

Platform	Post-FCS Program	Future Investment Planned	Create BoK
Class I UAV	None	Yes	Yes
Class II UAV	None	Yes	Yes
Class III UAV	None	Yes	Yes
Class IV UAV	None	Yes	Yes
MULE Transport (T) Countermine (C) ARV-A-L (A)	Net-Warrior (Transport variant called SMSS)	(T): yes (C): unknown (A): unknown	(T): No (C): Yes (A): Yes
ARV	TARDEC ATO	Unknown	Yes
SUGV	E-IBCT	Yes	No
UGS	None	Yes	Yes
NLOS-LS	Navy LCS	No	No
IMS	Scorpion	Yes	No

¹⁴⁵K. Pugh and N. M. Dixon, "Don't Just Capture Knowledge—Put It to Work," *Harvard Business Review*, May 2008, Vol. 86, No. 5, p. 21.

¹⁴⁶Kucera, 2005.

¹⁴⁷Bolton, "Memorandum for Program Manager, Future Combat Systems (Brigade Combat Team)," 2007.

Class II/III-like assets.¹⁴⁸ Thus we recommend a BoK be created from the Class II and III efforts, with the caveat that careful attention is paid to the technical reliability due to the short design life span of these platforms.

The Class I and IV UAV, developed by Honeywell and Northrop Grumman respectively, are continuing to mature through applications beyond the battlefield and development of next-generation versions. The Class I was cancelled in LRIP and received unfavorable ratings in LUT by the user community. However, given some of the technology advances made by the Class I, such as the design of a small heavy-fuel engine, it may be worthwhile to synthesize key design lessons from this effort. The Class IV was cancelled in 2010 in favor of modifying an existing Shadow UAV (Honeywell).¹⁴⁹ Despite the cancellation of these platforms, the Army's 2010–2035 UAS roadmap explicitly requires such capabilities. A BoK for all the classes of UAV developed in FCS would thus be a worthy investment.

The UGS (Tactical and Urban) are continuing to be developed by Textron Systems and underwent LUT as part of the E-IBCT program. Given the operational necessity for wireless sensor networking in the near-term and future battlefield, it seems worth the Army's investment to create a UGS BoK for next-generation sensors. Furthermore, since the LUT determined that the UGS "provided little tactical intelligence," there is clearly room for improvement in future sensor designs, which may benefit from leveraging the FCS UGS designs. In addition to sensor development, radio integration and wireless sensor networking will remain a challenge and thus warrants learning from the FCS experience.

Other contractors, such as McQ Inc., are also providing DoD unattended ground sensors, through either SBIR or production contracts,¹⁵⁰ and should thus benefit from the Army's investment in UGS development during FCS.

For the UGV, the three platforms made significantly different progress. The SUGV was arguably the most successful FCS platform and continues to be procured by the Army and developed by iRobot. Creating a BoK based on the SUGV may thus be less useful than ensuring that data rights are available to iRobot for any future variations of the SUGV. The MULE had three variants: Countermine, Transport, and Armed Robotic Vehicle Assault-Light. The Transport and Countermine versions were cancelled in January 2010, but work on the ARV-A-L was allowed to continue.¹⁵¹ How-

¹⁴⁸ U.S. Army UAS Center of Excellence, "Eyes of the Army: U.S. Army Roadmap for Unmanned Aircraft Systems, 2010–2035," Fort Rucker, Ala.: Army UAS CoE Staff, no date.

¹⁴⁹ Wasserbly, "US Army Axes UAS and Two UGV Models," 2010.

¹⁵⁰ McQ Inc., "McQ Inc. Celebrates over 25 Years of Pushing Technology to the Limits of Innovation," Fredericksburg, Va., May 9, 2011.

¹⁵¹ Wasserbly, "US Army Axes UAS and Two UGV Models," 2010.

ever a July 29, 2011 ADM officially cancelled work on the ARV-A-L, requiring all work to stop by the end of September.¹⁵²

Lockheed Martin continues to pursue a Transport variant in the guise of the Squad Mission Support System (SMSS) UGV. SMSS provides a portable power solution to the Army, complementing the Net-Warrior Soldier technology package,¹⁵³ and thus it seems less of a priority to create a BoK for MULE Transport, and more useful to ensure that Lockheed has sufficient data rights to access any relevant information from its MULE Transport development to support SMSS development. The countermine variant was highly dependent on the GSTAMIDS complementary program, so if a BoK is created, it would require sufficient integration of documents from GSTAMIDS, at least insofar as integration with the platform is concerned. However, it is unclear if the Army desires a UGV countermine capability.

The ARV-A-L variant would likely teach very similar lessons as the ARV Assault and RSTA platforms, which were returned to Army S&T for further development. Two TARDEC ATOs are focusing on robotic control and autonomous navigation.¹⁵⁴ Any BoK for the ARV or ARV-A-L would thus require integration of TARDEC knowledge and documentation from these supporting ATOs. However, it is unclear if the Army would invest in an armed UGV program.

The two unattended networked munitions, NLOS-LS (“missiles in a box”) and IMS (vehicle landmine alternatives) have outlived FCS. NLOS-LS was cancelled in E-IBCT but continues to be pursued by the Navy for the Littoral Combat Ship program. Ensuring that Lockheed, which is continuing to develop NLOS-LS for the Navy, has data rights from its FCS effort would thus be more prudent than investing in a BoK. IMS was separated in 2007 and is now part of the Army’s PM-CCS and is renamed Scorpion. In order to comply with the U.S. landmine policy directive¹⁵⁵ of 2004, networked munitions systems are still needed to replace persistent anti-personnel and anti-vehicle landmines. Although there is an explicit need for this capability, the continued development in PM-CCS warrants ensuring data rights to FCS material rather than investment in generating a BoK.

The overall utility of the MGCV BoK is not yet known, and must be assessed in the near term by surveying potential GCV contractors. Suggestions for improvement, such as the type of missing information or too many nontechnical details, can then also be incorporated into any BoK created for other platforms. If the MGCV BoK is to serve as a prototype for any other platform’s BoK, the utility it serves for potential GCV contractors must be determined before investing in creating a BoK for other platforms, which is a nontrivial investment of resources. As we have emphasized, to ensure the reliabil-

¹⁵² Kate Brannen, “U.S. Army Cancels MULE Unmanned Ground Vehicle,” *Defense News*, August 1, 2011.

¹⁵³ Lockheed Martin, “SMSS,” no date.

¹⁵⁴ These ATOs are called RVCA and NAUS.

¹⁵⁵ *Army Modernization Strategy*, 2010, Department of the Army, Office of the Deputy Chief of Staff for Programs.

ity of documents that form a BoK, those involved in the development of the platform must assess the technical quality even if the documents were graded for a system-level PDR. One natural choice may be the relevant IPT lead for the corresponding platform.

Increasing system or system-of-systems functionality generally leads to increased complexity from both a program management and a technology development standpoint. The challenges of synchronizations and consistent requirements across complementary programs may suggest that critical technologies be part of the core program.

The critical technologies associated with software-defined radios, JTRS and WIN-T, such as MANET protocols, quality of service, and cross-domain guarding, were challenging to develop. Would it have been better to include another radio solution as part of the core program? On the other hand, incorporating too much functionality into a program can also be challenging to manage programmatically and from a technology development perspective. Determining a manageable amount of functionality will be a challenge for future acquisitions, including past FCS functions, such as battle command and DCGS.

In order to determine the value of any technologies born of FCS efforts, it will be important to categorize not only finished prototypes, but also less refined products, such as designs, M&S, or testing solutions which may offer lessons for the future. At present, there is not a coherent effort to catalog the list of potential outputs.

One of the indirect outcomes of FCS is the development of technologies that may not have found support within the commercial sector, due to either a lack of utility or risk aversion. For example, software-defined radios have both commercial and military utility,¹⁵⁶ but it can be argued that risk aversion to new technologies may prevent commercial development at a similar pace. Any new technology faces the risk that it may not be widely adopted or supported by common standards. Military development of new technologies, as opposed to commercial development, has the potential advantage of requiring adoption while ensuring compatibility with existing technologies. However, DoD has an institution dedicated to advancing the state of the art for various technologies, namely DARPA, and it is unclear that the Army can produce the same kind of success from high-risk, high-payoff technology development.

Conclusions and Lessons

Our examination of the FCS program from a technology development perspective elicits lessons that speak to the challenges of developing multiple novel technologies from a broad range of sources.

¹⁵⁶USAF has SDR interests expressed through SBIR programs.

Capture Technical Lessons from System Development

There are two categories of systems from FCS for which there is a future need: those continuing to be developed by the same contractor in other programs, perhaps with some variation; and those without a follow-on effort. For the first category, ensuring that the contractor has data rights from FCS may be more valuable than expending resources to create a BoK. However, for the second category of platforms, creating a BoK-like repository would certainly provide a tangible return on investment and perhaps instill a program management discipline of capturing technical lessons, even from prematurely cancelled programs. If a platform does fall into the second category, but the Army's future investment plans for that capability are unknown, further cost-benefit analysis will be required to justify the investment of generating a BoK, which nonetheless would capture technical lessons.

Collect Technical Outputs Using the AMSAA System Book as a Guide

There has been no complete accounting of FCS technologies and systems, and it remains certain that some technologies and efforts from FCS will be lost because of that. One possible strategy to remedy this situation is to create a checklist based on the AMSAA System Book,¹⁵⁷ which served as a reference to key technologies and capabilities, albeit for the less ambitious original intent associated with FCS systems for mission-level analysis of SoS. These capabilities can then be catalogued by associated deliverables, end-state status (simulation model, prototype, etc.), and present ownership (PEO, PM, or contractor).

¹⁵⁷ U.S. Army Materiel Systems Analysis Activity (US AMSAA), "Army Future Combat Systems Unit of Action System Book," v.3.02, March 22, 2003.

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