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Lessons from the Army's Future Combat Systems Program

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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 management; 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 architechting (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.