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APPLYING A SYSTEM-OF-SYSTEMS ENGINEERING PERSPECTIVE TO CURRENT AND FUTURE ARMY ACQUISITIONS

by

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ABSTRACT

This study uses core elements of the system-of-systems (SoS) engineering process to obtain lessons learned, which are then used to recommend process and organizational changes to facilitate an SoS approach to current and future U.S. Army acquisitions. The study finds that an SoS approach is necessary to accommodate the capability-based process that drives the Army acquisition system. Recommendations include incorporating SoS engineers in the Joint Capabilities Integration Development System process to build and standardize SoS architectures; using a chief integration officer throughout the SoS life cycle to provide expertise on integration and interoperability; and establishing guidelines for integrated product teams and lead system integrators. The SoS acquisition approach will also benefit from capability portfolio managers using consolidated funding as opposed to the current stove-piped funding. The SoS wave model can be incorporated in the operation and support phase to support iterative SoS evolution. The Army acknowledges that many current systems are, or have the potential to be, part of an SoS environment; however, the current acquisition processes and organizational structure are based on stand-alone system acquisitions. The recommendations of this study describe how the Army can support SoS acquisition.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAWO	Army Asymmetric Warfare Office
ABCS	Army Battle Command System
AFATDS	Advanced Field Artillery Tactical Data System
AMDPCS	air and missile defense planning workstations
AMDWS	air and missile defense workstation
AOR	area of responsibility
AR	Army Regulation
ASALT	Assistant Secretary of the Army for Acquisition Logistics and Technology
ASAS	All Source Analysis System
ATEC	Army Test and Evaluation Command
AV	aviation
BCCS	battle command common services
BCS3	Battle Command Sustainment Support System
BFT	Blue Force Tracker
BMDS	ballistic missile defense system
BTF	Biometric Task Force
CDD	capabilities development document
CPOF	command post of the future
C-RAM	counter rocket artillery mortar
CS	capability set
CSA	Chief of Staff of the Army
CSIS	Center for Strategic and International Studies
CWIS	close-in weapon system
DA	Department of the Army
DARPA	Defense Advanced Research Projects Agency
DCGS-A	Distributed Common Ground Station–Army
DOD	Department of Defense
DODAF	Department of Defense Architectural Framework
DOT&E	Director Operational Test and Evaluation

DOTMLPF	doctrine organization training materiel leadership education personnel facilities
EW	electronic warfare
FAAD C2	Forward Area Air Defense Command and Control
FBCB2	force battle command brigade and below
FCS	future combat systems
FOB	forward operating base
FOC	fully operationally capable or functional operating capabilities
GCCS	Global Command and Control System
GCS	ground combat systems
HMMWV	high-mobility multipurpose wheeled vehicle
ICD	initial capabilities document
ICV	infantry carrier vehicle
IPT	integrated product team
JCIDS	Joint Capabilities Integration Development System
JROC	Joint Requirements Oversight Council
JUONS	joint urgent operational needs statement
LB	LandWarNet/Battle Command
LSI	lead system integrator
MCS	mounted combat system
MDA	Missile Defense Agency
MDAP	major defense acquisition program
MDMP	military decision-making process
NLOS-M/C	non-line of sight mortar/cannon
OIF	Operation Iraqi Freedom
ORD	operational requirements document
OSD	Office of Secretary of Defense
OV-1	high-level operational concept graphic
PASS	publish and subscribe system
PEO	program executive officer
PM	program manager
POM	program objective memorandum

POR	program of record
PPBE	Planning, Programming, Budgeting, and Execution
RDECOM	Research Development and Engineering Command
SAIC	Science Applications International Corporation
SE	systems engineering
SoS	system of systems
SV-8	system evolution description
SV-9	system technology forecast
T&E	test and evaluation
TAIS	Tactical Airspace Integration System
TCM	TRADOC capability manager
THAAD	Terminal High Altitude Air Defense
TRADOC	Training Command
TV-2	technical standards forecast
UAV	unmanned aerial vehicle
UEWR	Upgraded Early Warning Radar

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EXECUTIVE SUMMARY

The Army acquisition process is tailored to specify, develop, and acquire individual systems. This is evident in the policies, processes, and organizational structure of the acquisition workforce. Systems engineering is often found in Army policy and acquisition guidelines, but system-of-systems (SoS) engineering is not. This study determined that, based on the increasing need for systems to be interoperable with one another, an SoS approach to acquisitions is more suitable for current and future acquisition programs. This study used core elements of SoS engineering to analyze past Army SoS acquisition efforts, and used the lessons learned to recommend process and organizational changes that would enable the Army to go from a systems approach to an SoS-based approach for future acquisitions. The main process change recommendations are that the Army should:

- utilize DODAF for current and future Army acquisitions, and apply DODAF to document the SoS architecture.
- formally incorporate a Department of Defense Architecture Framework (DODAF) high-level operational concept graphic(OV-1) for SoS concept of operations (CONOPS) development and consider adding other DODAF models as mandatory model requirements for the acquisition process;
- mandate that private firms demonstrate the ability for technology developments to integrate with an existing or future SoS—further, the Army should reward private firms that demonstrate innovative ways to use technologies to integrate existing or future systems into an SoS;
- initially allocate funding at the SoS level, and divide up funding into constituent systems based on each system’s objectives during an SoS acquisition;
- simultaneously test as many SoS constituent systems as feasible during the system development and demonstration phase and clearly state assumptions used during testing—these assumptions must be clearly articulated in the test plan, and the test plan also must describe the impacts to the system if the assumptions do not hold true;

- have the program manager (PM) evaluation process emphasize the PM's efforts to integrate his or her program into its SoS framework; and
- use the SoS wave model as an assessment tool for SoS architectural evolutions and future SoS updates.

This study found that some of the organizational changes that could be incorporated are:

- The Army should train and designate SoS engineers as mandatory stakeholders in the Joint Capabilities Integration Development System (JCIDS) process for Army acquisitions.

- A Chief Interoperability Officer can be assigned to all future Army acquisitions early in the process. This officer will be the authority on all interoperability issues, and ensure that interoperability objectives are met in the JCIDS process.

- The Army can train personnel in order to make the organizational role of Lead System Integrator LSI a government function, or at a minimum oversee private companies that assume this role.

- Capability portfolio managers can be assigned at the PEO level, and current and future SoS acquisitions can be organized based on the capability manager's area of responsibility as opposed to the program executive officer (PEO's).

The study concludes by discussing additional research that can be conducted in the areas of SoS engineering and Army acquisition.

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I. INTRODUCTION

The Department of Defense (DOD) acquisition process has changed several times over the past fifty years (Fox 2012). According to Fox, it was not until 1960 that the DOD actually adopted a formal acquisition strategy. From 1966 to 2001, there have been over sixty acquisition reform initiatives attempting to solve the complex issues that are characteristic of the DOD acquisition process (Fox 2012). These reforms have led to some improvements, but the acquisition process still faces many challenges in balancing cost and schedule efficiency while maximizing the capability gained from system development.

During the early 1990s, the acquisition strategy used a threat-based approach (Dickerson 2014). Decision makers analyzed current and future threats and developed systems designed specifically to counter these threats (Dickerson 2014). Looking at the conflicts in which the United States was involved during the 1990s, one can see the variety of potential threats the United States had to mitigate. For example, although the Cold War was coming to a close in 1990, the Russian threat was not completely eliminated. Desert Storm was taking place in the early 1990s, as well as conflicts in Bosnia/Kosovo, Somalia, and Afghanistan. As threats evolved, acquisition systems became bigger and more complex in order to counter a variety of threats from different nations in different environments. Major defense acquisition programs (MDAPs), which are programs that exceed a certain cost threshold, became commonplace. These systems' total operating costs typically range from the hundreds of millions to billons, and often take years to develop.

In 2003, the DOD established the Joint Capabilities Integration and Development System (JCIDS), which represented a shift in acquisition strategy from threat-based to capability-based (Fox 2012). This process replaced the outputs from a requirements-based analysis—the operational requirements document and mission need statements—with the initial capability document and capability production document, with output based on a capability analysis. The JCIDS process requires sponsors, usually Combatant Commanders, to take guidance given in several strategic guidance documents, such as *the*

National Security Strategy (NSS), the National Strategy for Homeland Security, the National Defense Strategy, and the National Military Strategy (DOD 2015). The Joint Requirements Oversight Council (JROC) reviews these capabilities, and decides whether or not a materiel or non-materiel solution is needed. A materiel solution consists of a physical object or objects that form a system. A non-materiel solution consists of a change in policy or training that could achieve the capability. If a materiel solution is needed, then the defense acquisition process begins. The diagram in Figure 1 illustrates the major systems in the acquisition processes. One can see from Figure 1 that all of these systems must be integrated effectively in order to produce a successful acquisition. The Planning, Programming, Budget, and Execution (PPBE) system is responsible for planning and tracking programs from a cost perspective. The acquisition process as described in Department of Defense Instruction 5000.02, deals with the design and build of a materiel solution for a particular capability gap, and the JCIDS process identifies and prioritizes the capability gaps based on the national defense strategy.

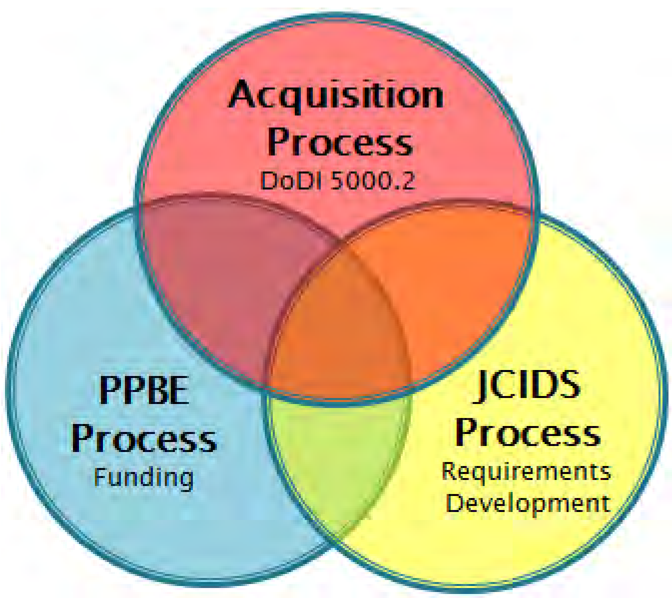

Figure 1. DOD Procurement Systems (from DOD 2015)

Some of the motivations for the shift from a requirements-based process to a capability-based acquisition approach can be gleaned from former Secretary of State Rumsfeld. In a speech in 2001, Rumsfeld stated that the legacy of acquisition processes is "really a relic of the Cold War—a holdover from the days when it was possible to forecast threats for the next several decades" (Garamone 2001, 1). In the same speech, Rumsfeld noted the need to eliminate redundant processes and capabilities that occur when a new system is created every time a new threat emerges. Capability-based acquisition also mitigates the tendency to look to a new system for a solution as opposed to looking at existing systems for solutions. This new capability approach placed a new emphasis on developing SoS. System-of-systems combine individual systems to achieve greater capabilities than the individual systems could achieve by themselves (Office of the Deputy Under Secretary of Defense for Acquisition and Technology, Systems and Software Engineering [OSD] 2008).

The SoS concept came to the forefront in a vision established in the late 1990s, described by Charles Dickerson (2014) in his chapter of *Systems of Systems Engineering: Principles and Applications* as a "revolution in military affairs." This revolution of military affairs transitioned from the conventional force-on-force that characterized the Cold War era to a networked arms warfare that required agility and flexibility. According to Dickerson, the rise of the Internet during this time led to senior leaders envisioning a battlespace in which hardware and software systems could be integrated across multiple platforms. The benefits of this approach would be increased situational awareness, faster communications, and quicker and more precise execution. Additionally, network-based acquisition approach would facilitate joint operations, which have become commonplace in military operations. In the Army, specifically, leaders envisioned commanders being able to track their assets on the battlefield through software (Dickerson 2014). By the early 21st century, the Army shifted from platform-based to network-based operations (Dickerson 2014). The structure for using SoS to achieve this network-centric concept can be seen in Figure 2.

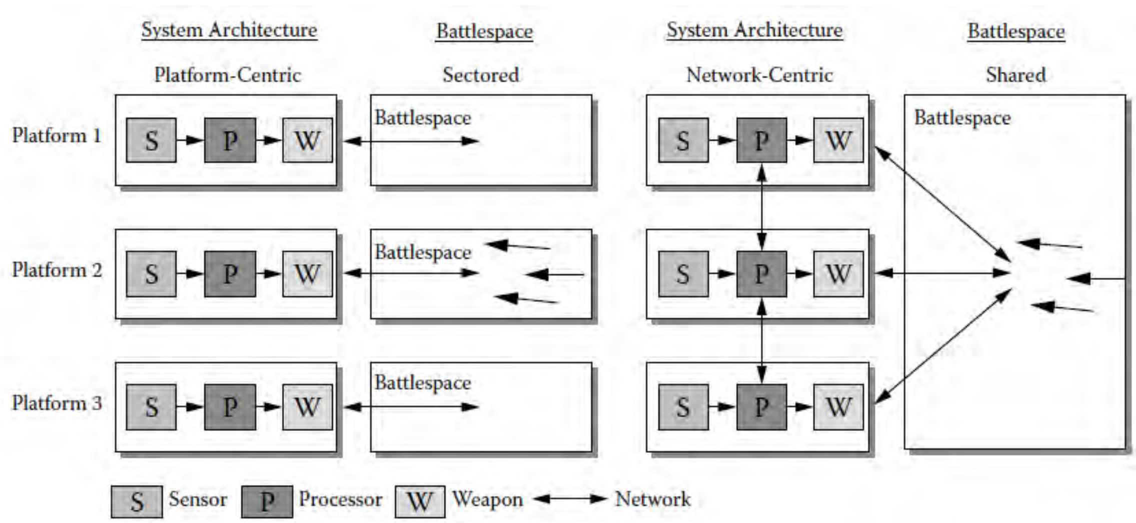

Figure 2. Comparison of Platform Centric Systems Architecture with Network-Centric Systems Architecture (from Dickerson 2014)

On the left side of the diagram in Figure 2, there are three weapon platforms, each with its own battlespace. In this case, the network connectivity of each platform does not extend outside of the particular weapons battlespace, and there is no connectivity between weapon platforms. On the right side, the diagram describes a networked systems architecture in which all weapon platforms are connected and integrated into a single battlespace. This illustrates the potential of a networked system of systems. When the Army moved toward a network-centric approach, the increased connectivity also added complexity to systems and SoS. With this rise in system complexity, there was a renewed emphasis on the systems engineering process, which facilitated the creation of many individual systems. By 2009, there were ninety-six individual DOD MDAPs that were in various phases of the acquisition process (Fox 2012). The current systems engineering process for individual systems can be seen in Figure 3.

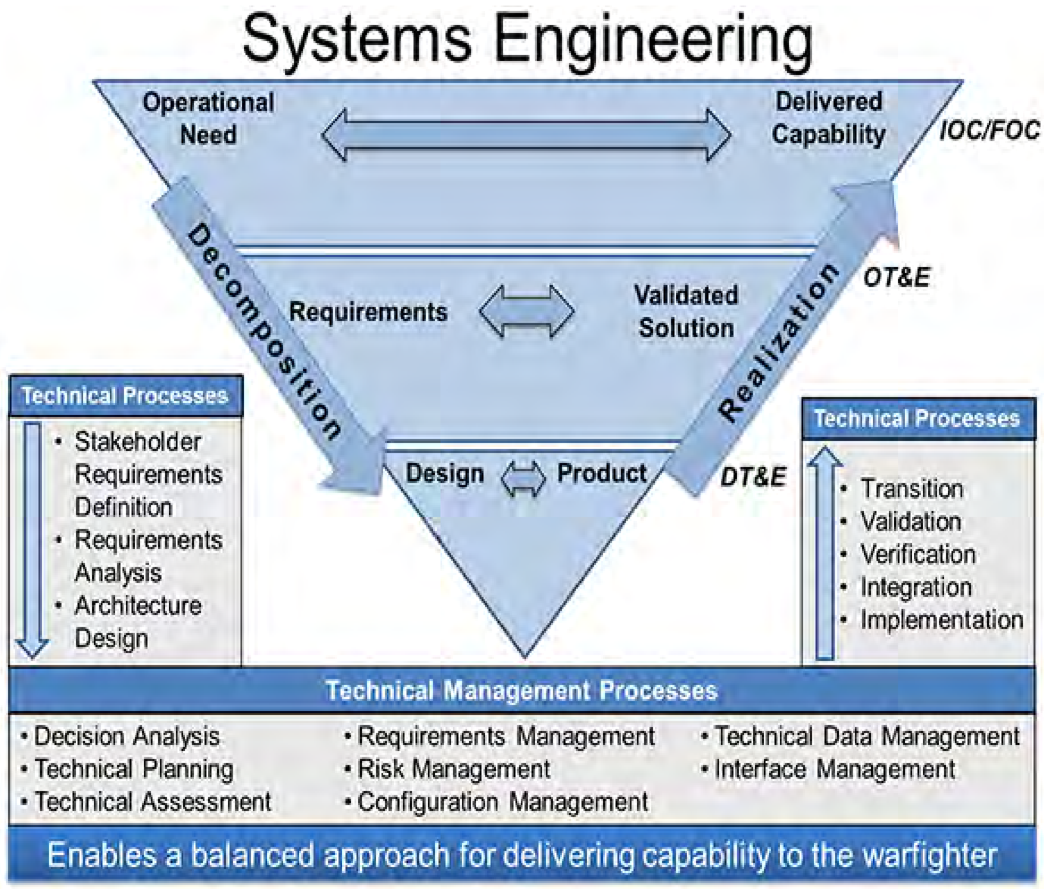

Figure 3. Individual Systems Engineering Process for Acquisitions (from Manning 2014)

As seen in Figure 3, the systems engineering process starts with an operational need and ends with a delivered capability. The technical processes going up and down the V are described in the adjacent boxes, and the technical management processes are used throughout the systems engineering process.

Over the past five years, the DOD has made an effort to incorporate system of systems engineering into the acquisition process. Evidence of this can be seen with the DOD SoS Guidebook published in 2008 (OSD 2008) and the Navy's draft SoS Engineering Guidebook released in 2011 (Office of Assistant Secretary of the Navy (Research, Development, Acquisition) [OASN (RDA)] 2006). The intent of incorporating SoS engineering would be to explore the idea of integrating existing systems, as opposed to creating new systems to fill capability gaps. Currently, the Army does not have a service-specific guide for SoS engineering. This thesis explores taking a deliberate effort to integrate existing and future Army programs into a system of systems. This would align with the Army's plan according to the Army Acquisition Policy, AR 70-1, which is to approach all materiel acquisitions from an SoS perspective (Department of the Army 2011). It further discusses organizational changes that would have to take place in order to facilitate such an effort.

A. OBJECTIVE

The objective of this research is to examine the acquisition process from an SoS perspective and identify lessons learned and best practices from past Army attempts to implement SoS. Additionally, this research looks at current SoS engineering processes and organizational changes that must take place in order for the Army to successfully integrate its existing programs into an SoS. The goal of this thesis is to provide a starting point for a possible cultural shift away from the individual system approach to an SoS approach for addressing capability gaps.

B. PROBLEM STATEMENT

The problem that the Army is currently experiencing is that although several Army systems are integrated at some level, the Army acquisition policies and procedures are structured based on addressing capability gaps using an individual system approach. This is evidenced by the focus on individual systems in Army acquisition regulations (such as the AR 70-1) and guidelines (such as the Department of the Army Pamphlet 70-3 [DA PAM 70-3]). These individual systems are becoming more complex, requiring more resources, and several have been cancelled due to cost or schedule overruns. Although the systems engineering process is commonplace for individual system acquisition, systems engineering for SoS rarely takes place, if it takes place at all. This is evidenced by the fact that the systems engineering for SoS is not explicitly addressed in Army acquisition regulations. This thesis addresses the need for the Army's next major program to make a deliberate effort to implement the systems engineering process for SoS, and the organizational changes that must take place in order for the Army to effectively implement systems engineering for SoS.

C. RESEARCH QUESTIONS

This thesis attempts to answer the following questions in order to recommend process and organizational changes to the current acquisition system that facilitate an SoS approach to current and future Army programs:

1. What are some of the lessons learned and best practices that can be gleaned from the Army's past attempts at SoS acquisitions?

2. What current processes in the Army acquisition system should change, be created, or be implemented as policy in order to facilitate systems engineering from an SoS perspective?

3. What organizational changes in the Army need to take place to facilitate a successful SoS engineering process?

D. SCOPE

This thesis is intended to apply to all current and future Army acquisition programs; however, this thesis will focus on three previous SoS acquisitions as case studies to recommend process and organizational changes to the acquisition system. Due to the extensive number of Army programs, the research does not detail how particular Army programs could be integrated into an SoS architecture, but it does focus on lessons learned and best practices to set the conditions for all current and future programs to be integrated into an SoS architecture. Additionally, this thesis examines the organizations involved in the primary steps of the acquisition process and recommends changes to facilitate the systems engineering process from an SoS perspective.

E. METHODOLOGY

This thesis discusses some of the policy and doctrinal changes that led to the acquisition of SoSs. It then defines different SoS types and details the core elements of SoS engineering. This thesis also details the steps of the acquisition process and the personnel and processes involved. The research uses the seven core elements of SoS as described in the DOD SE guide for SoS (OSD 2008) as a framework to analyze past Army SoS programs and determine what was done successfully as well as areas for improvement. The report concludes with procedural and organizational recommendations for implementing an SoS engineering approach to current and future Army acquisitions.

F. THESIS ORGANIZATION

Chapter II of this thesis is a literature review, which focuses on the Army SoS and its role in the acquisition process; it concludes with a discussion of the core elements of SoS engineering. Chapter III analyzes three past Army SoS programs using core elements of SoS engineering as described in the DOD SE guide. The chapter concludes with lessons learned, which are used to recommend process and organizational changes in the following chapters. Chapter IV looks at the major processes of the acquisition process, and discusses process changes or additions needed in order to facilitate the systems engineering process for SoS. Chapter V examines the organizations involved in the acquisition process and recommends changes to facilitate the system engineering process for SoS. Chapter VI concludes with a summary of recommendations and areas for future research.

II. LITERATURE REVIEW

In order to go forward with the analysis of SoS and realize how it relates to the Army acquisition process, it is important to understand certain definitions and processes that are relevant to SoS during the acquisition process. The DOD defines a system as a "functionally, physically, and/or behaviorally related group of regularly interacting or interdependent elements; that group of elements forming a unified whole" (OSD 2008, 3). An SoS is "a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities" (OSD 2008, 4). According to the SoS SE guide's definitions of a system and an SoS, the distinction between the two is that once a system is established and is broken down into its components, the components cannot be the same (OSD 2008). An example of this can be seen with a car. Once the engine and doors and wheels are separated from the car, the components cannot perform the same functions that they could as part of the total car system. On the other hand, with an SoS, individual systems can theoretically break away from the SoS and provide useful capabilities. An example of this is two systems connected by a network, such as iCloud. Both a smart phone and computer can share data through an iCloud but each system can also function independently. The flexibility inherent in an SoS is an important concept because it allows some flexibility with individual systems. The constituent systems of an SoS can be attached and detached from without losing their individual system identity.

An SoS is different from a family of systems. A family of systems is "a set of systems that provide similar capabilities through different approaches to achieve similar or complementary effects" (OSD 2008, 4). The distinction here lies in the capability. For example, the Stryker and the high-mobility multipurpose wheeled vehicle (HMMWV) would be considered a family of systems because they both provide similar capabilities. Both are used as methods of transportation for soldiers, and both vehicles have the capability to mount weapon systems for security. The Stryker has a greater personnel capacity and the armament is better than the HMMWV, but the combination of both of these vehicles does not provide any unique capabilities. On the other hand, the Ballistic

Missile Defense System is a true SoS because the Air Force's Upgraded Early Warning Radar (UEWR) combined with a Patriot System provides unique capabilities unavailable from the constituent systems. The UEWR can detect missiles early in the incoming missiles flight and can cue the incoming missile with the Patriot System so that the Patriot can engage the missile at the optimal time. The UEWR alone cannot intercept any missiles, but it has a great range for missile detection. The Patriot System radar can detect missiles, but it does not have the sensor range of the UEWR. These two systems combined as well as several other systems in the ballistic missile defense SoS come together to provide greater capabilities against missile threats.

An SoS, such as the Ballistic Missile Defense System (BMDS), comes into existence under different circumstances. These circumstances can be categorized into one of four types of SoS, as illustrated in Table 1.

Table 1. Categories of SoS (from MITRE 2014)

Type	Definition
Virtual	Virtual SoSs lack a central management authority and a centrally agreed-upon-purpose for the system-of-systems. Large-scale behavior emerges—and may be desirable—but this type of SoS must rely on relatively invisible mechanisms to maintain it.
Collaborative	In collaborative SoSs, the component systems interact more or less voluntarily to fulfill agreed upon central purposes. The Internet is a collaborative system. The Internet Engineering Task Force works out standards but has no power to enforce them. The central players collectively decide how to provide or deny service, thereby providing some means of enforcing and maintaining standards.
Acknowledged	Acknowledged SoSs have recognized objectives, a designated manager, and resources. However, the constituent systems retain their independent ownership, objectives, funding, development, and sustainment approaches. Changes in the systems are based on collaboration between the SoS and the system.
Directed	Directed SoSs are those in which the integrated system-of-systems is built and managed to fulfill specific purposes. It is centrally managed during long-term operation to continue to fulfill those purposes as well as any new ones the system owners might wish to address. The component systems maintain an ability to operate independently, but their normal operational mode is subordinated to the central managed purpose.

An example of a virtual SoS is the DOW Jones Industrial. Shareholders and CEOs have some level of control over the individual companies or systems that make up the DOW, but there is no central authority that manages the DOW as a whole. Financial capital, which often is fueled by consumer confidence, is the mechanism that maintains the DOW. It is relatively invisible because individual investors will buy and sell the stock based on their personal beliefs about a particular company. One can only speculate the reasons why the DOW may go up or down.

One property that is especially prevalent in a virtual SoS is emergence. Emergence, as stated by Charles Keating, occurs when “patterns/properties in a complex system will come about (emerge) through operation of the system. These patterns/properties cannot be anticipated beforehand and are not capable of being deduced from understanding of system constituents or their individual properties” (Keating 2014, 170). Emergence occurs in systems and SoS. In a virtual SoS, there is little to no planning for emergence, so with the example of the DOW, there are numerous trades taking place during the day by millions of people. This could cause the DOW to rise significantly. This may lead to emergent behavior such as investors believing that the DOW is overvalued and consequently beginning to sell, or it could cause companies to make a business decision based on the DOWs perceived value that reverses the upward trend. These emergent behaviors can produce both positive and negative consequences.

The Internet, as stated in Table 1, is a collaborative SoS. Information comes from many different sources, but can be monitored, and, if necessary, censored by federal authorities. Several nations around the world censor information available on the Internet, usually through their government. In this regard the Internet is a collaborative SoS because each nation has its own way of monitoring and regulating the information that is seen on websites. Additionally, various websites come together to provide diverse information on a myriad of topics. Different nations have different standards, and although each nation is able to centrally manage information in their respective nations, there is no global authority that controls what is posted on the Internet. In this sense, the Internet is virtual, with no central authority and no central agreement on the purpose of the Internet.

Acknowledged and Directed SoSs are more commonplace in the DOD. An example of an acknowledged SoS is the BMDS. All systems in the ballistic missile defense system come together to combat a common threat of intercepting ballistic and cruise missiles launched by land, sea, or air. Each system within the BMDS is managed separately and has its own line of funding. For example, the Terminal High Altitude Defense (THAAD) system is managed by the Army while the Aegis system is managed by the Navy. The BMDS SoS is managed by the missile defense agency (MDA). The

MDA is primarily responsible for integrating these individual systems. According to the DOD systems engineering guide, “most military systems are part of an SOS even if they are not explicitly recognized as such” (OSD 2008, 4). This suggests that most DOD SoSs are acknowledged as opposed to directed. Although the ballistic missile defense system is an acknowledged SoS, the missile defense agency does not explicitly state that BMDS is an SoS. It refers to BMDS as “the system” on its webpage, and the individual systems as “elements” (Missile Defense Agency 2014). The term elements suggest that each part of the BMDS is not a system in itself. This is characteristic of several Army programs. These programs are acknowledged as an SoS, though a lot of the terminology and processes resemble a system.

The last category of SoS is the directed SoS. The most recent example of an Army-directed SoS is the Army Future Combat Systems (FCS). This is the most significant attempt at an Army SoS. This was a first for the Army, and the Army has not attempted to design and build a directed SoS since the FCS. The FCS was initiated in 2003 with the intention of transforming the Army into a lighter, more agile force. This program was intended to function as an SoS, and was centrally managed by high-ranking Army and civilian personnel. According to a RAND study, this was the “most ambitious acquisition program in Army history” (Pernin et al 2012, iii). The program was cancelled in 2009 for a variety of reasons. An in-depth analysis of the decisions and processes followed during the acquisition of the FCS occurs in subsequent chapters.

A. SYSTEMS ENGINEERING IN SOS

Most of the processes that occur throughout any system’s lifecycle are influenced by the systems engineering process. The systems engineering process grew out of a need to analyze programs holistically. It can be traced back to the 1960s, when Secretary McNamara and his staff through the DOD Reorganization Act of 1958 created the Office of Systems Analysis (Fox 2012). This was in response to several cost and schedule overruns that occurred in programs such as the C-5A, the F-111, and the SRAM-A (Fox 2012). The Systems engineering process continued to develop in later decades, and became a discipline in several universities by the late 1990s. Currently, the systems engineering process is mandated in the Army Acquisition Policy, AR 70-1. The policy states, “Regardless of the acquisition category, all programs shall develop and follow a systems engineering plan to execute and manage a disciplined systems engineering process supporting the acquisition strategy adopted by the program” (Department of the Army 2011, 41). Therefore, it is logical that systems engineering processes would play a significant role in SoS as well. Although the Army specifically mandates that a systems engineering process must be implemented throughout the entire life cycle of the system, there is no mention of an SoS engineering process to guide the SoS acquisition process. Systems engineering for a system and an SoS is very different. The chart in Table 2 compares the systems engineering and SoS engineering considerations.

Table 2. Comparison of SE for a System and SoS (from Dahmann 2014)

	System	System of Systems
Management /Oversight		
Stakeholder Involvement	Clear set of stakeholders	Added levels of complexity; stakeholders at both system level and levels with competing interests and priorities; in some cases the system stakeholder has no vested interest in the SoS
Governance	Single PM and funding	May have management and funding for the SoS but also have management and funding of for individual systems
Operational Environment		
Operational Focus	The systems are designed and developed to meet operational objectives	SoS is called upon to meet a set of operational objectives using systems whose objectives may or may not align with the SoS objectives
Implementation		
Acquisition/Test & Validate	Established process aligned to ACAT milestones, specified requirements, SE with a systems engineering plan (SEP)	No established process across multiple system lifecycles across acquisition programs, involving legacy systems, developmental systems, and technology insertion
	Testing or validating the system is possible	Testing is more challenging due to the difficulty of synchronizing across multiple systems life cycles; testing all permutations, given the complexity of all the moving parts, is not possible
Engineering		
Boundaries and Interfaces	Focuses on boundaries and interfaces for the single system	In SoS the focus is on identifying the systems that contribute to the SoS objectives and enabling the flow of data, control and functionality of the SoS within the constraints of the systems
Performance & Behavior	Optimize performance of the system to meet performance objectives	Provide end-to-end performance across the SoS that satisfies user capability needs within the context and constraints of the systems

Based on the table, some of the key differences in the systems engineering processes deal with management. The systems engineering process frequently deals with gathering information from stakeholders and addressing their perspectives in the system. While a system may have stakeholders with multiple perspectives, stakeholders are all focused on the system, whereas in the SoS environment, stakeholders may or may not be vested in the SoS, and each stakeholder perspective may represent a different system. Another aspect of systems engineering is the relationship between the systems engineer and the program manager. Systems generally are assigned one program manager (PM), and in an SoS there usually is an SoS manager that must coordinate with several PMs. The relationship between the systems engineer and the SoS manager is different from the relationship between a systems engineer and project manager because the SoS manager has limited influence on the individual systems, whereas the program manager usually has influence over the system subcomponents.

Systems engineering is also focused on testing. The chart in Table 2 describes how testing is more difficult for an SoS because different systems may be in different development stages, which usually precludes testing the entire SoS. Consequently, testing rarely occurs at the SoS level. The constituent systems that make up the SoS usually are tested without the benefit of integration testing. The lack of integration testing places the SoS at risk of operational failure when the SoS is fielded for operational use. Furthermore, the systems engineering process focuses on establishing boundaries so that the system has the proper scope. This is challenging when dealing with SoS because systems are coming in with established boundaries, and changing these boundaries to accommodate an SoS may not align with the stakeholders' intended use for the individual system. Based on the differences between systems engineering and SoS engineering, it is important for the Army to emphasize these differences in Army acquisition policy. The systems engineering guide for the DOD discusses core elements of SoS engineering. Figure 4 shows the core elements and the relationships between them.

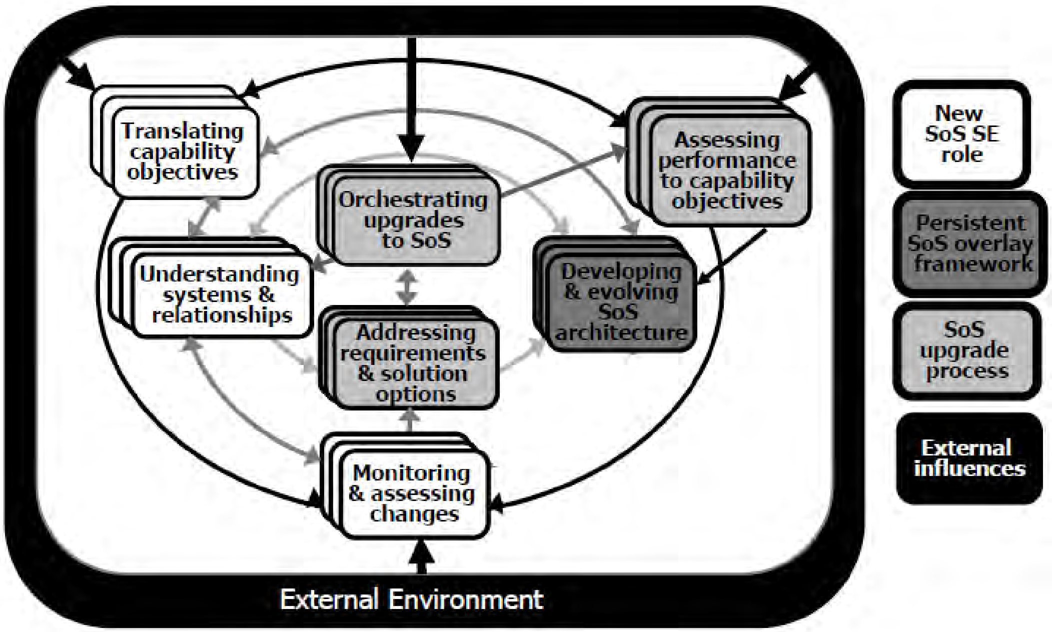

Figure 4. SoS Core Elements and Their Relationships (from OSD 2008)

B. CORE ELEMENTS OF SOS ENGINEERING

These seven core elements are described in detail in the SoS System Engineering (SE) Guidebook (OSD 2008), and will serve as the analytical framework for Army SoS programs in later chapters. The seven elements are discussed briefly in the following section.

(1) Translating Capability Objectives

An important part of the acquisition process is taking the capability objectives established during the JCIDS process and translating them to a materiel solution, if required. Capability objectives for an SoS are often very broad in nature (OSD 2008), and must be refined during the SoS SE acquisition process in order to accurately portray the way each constituent system will work together to achieve the desired capabilities. An example of a broad capability is to facilitate data transfer between multiple platforms. This capability must be refined to describe the interoperable capability that each platform must have, and the type of data each system must be capable of transferring. Furthermore, the SoS manager must be able to articulate what part each system will play in providing the overall capability required. This is often easier to glean from a functional decomposition of a single system. In an SoS, there will be a functional decomposition of all the constituent systems, and possibly an additional functional decomposition that traces the functions of the constituent systems with the overall capability objectives. Although the SoS SE guide states that SoS engineers operate under the assumption that all constituent systems go through the systems engineering process, the SoS Systems engineer will at a minimum have to understand the way each system’s functions contribute to the overall objective. This understanding is necessary to facilitate a capability to requirements crosswalk that is essential in systems engineering.

(2) Understanding System Relationships

If the SoS manager or engineer does not understand the relationships between the subordinate systems, the SoS will be at risk of not meeting capability requirements, or risk significant cost and schedule overruns. In essence, the SoS will likely fail in the long run if relationships between systems are not understood. Understanding system relationships goes beyond how the physical components are related and how they interface. Understanding system relationships means understanding the boundaries and constraints of each system (OSD 2008). These could be cost and schedule constraints or constraints imposed by political figures. The challenges associated with administrative relationships could be more difficult to overcome than the challenges stemming from physical component relationships. This does not mean that the physical component relationships should be ignored. Software and networking are a growing part of the acquisition process. An SoS engineer must understand the interface requirements for each subordinate system in order to assess technological and financial risks associated with SoS integration. The SoS engineer must also be mindful of how these relationships will change over time when one individual system retires or upgrades.

(3) Assessing Performance to Capability Objectives

In systems engineering, capabilities are usually mapped to functions, and functions are assessed based on measures of performance and measures of effectiveness. Measures of performance for an SoS may conflict with measures of performance of a constituent system. An individual system may have to perform sub-optimally in order for the SoS to perform optimally (OSD 2008). For example, a sensor on a particular weapon system may function optimally when its sensor is actively searching; however, when the weapon system operates in an SoS, the weapon system may cause interference for another sensor with greater detection range. This may require that the first system turn off its sensor and depend on the second system to do target searching. In this case, the first system is not in its optimal state, but it still has a weapon system that will make the SoS function optimally with assistance from the second system's sensor.

The assessment of a function's ability to meet its objectives is usually solidified through operational testing of the system (OSD 2008). This becomes more challenging when dealing with SoS. In order to conduct an operational test on an SoS, all of the individual systems must be at a point where they can be operationally tested. This means that coordination between the SoS manager and the subordinate systems is essential in order to facilitate operational testing. Oftentimes, operational testing before fielding is not feasible based on the constraints of the subordinate systems. As a result, most SoS testing is done through simulation (OSD 2008). There are always limitations when dealing with simulations because certain assumptions must be made. Further, these assumptions in simulation can result in a limited ability to capture the emergence that occurs when actual systems interface with each other. It is therefore important to understand and articulate the risk associated with the data that comes from simulation testing on an SoS. If possible, the actual systems should be used to conduct operational testing. This will yield the most accurate results, and possibly be a good investment that mitigates the cost incurred from employing a system based on inaccurate data.

(4) Developing and Evolving SoS Architecture

The Department of Defense architecture views (DODAF) provide guidelines on ways to display the architecture for systems and SoS. The SoS SE guide states that requirements often evolve from architectural views and architectural views evolve from requirements. Important architectural views for an SoS must address the relationships between constituent systems (OSD 2008). This can be done with a high-level operational concept graphic (OV-1) that details the concept of operations for the SoS. Viewing the system from an operational perspective allows stakeholders to see how the system achieves its required capabilities. There are several other SoS architectural views in DODAF that can be utilized based on the requirements of the specific SoS. In addition to developing the baseline architecture, SoS architecture must evolve to accommodate the dynamic nature of an SoS. SoS architecture should account for changes in individual systems. For example, if a system upgrades its software, interface views should be updated to reflect the software upgrade's impact on the SoS. This holds true for a system that may be retired as well, as this will certainly have an impact on the SoS.

(5) Monitoring and Assessing Changes

It is important to keep track of changes in the constituent systems because they may have an effect on the SoS. For example, an upgrade on the software of a particular system could affect the interoperability between that system and other systems. Similarly, changes in physical components also must be accounted for, as they may affect physical connections between other systems. It is important that these changes are planned in advance so that the effects on the SoS can be assessed. In addition to technical changes to the systems, there are changes to the programs. SoS managers must be cognizant of any changes in funding for constituent systems. For example, in the event of a sequestration where several budgets are cut, the SoS manager must understand the implications of the funding changes and how the funding limitations impact SoS performance.

It is important for SoS managers to document configuration changes in individual systems in case changes degrade SoS performance (OSD 2008). The SoS may need to go back to a baseline configuration if interoperability issues arise from physical or software upgrades in constituent systems. This would not be possible without a robust configuration management plan with detailed documentation. SoS may have to accommodate changes in subordinate systems, so this may warrant a bottom-up analysis to determine the effect of a constituent system change on the SoS.

(6) Addressing Requirements and Solution Options

In systems engineering, the analysis of alternatives focuses on system components and how they will best achieve the required capabilities given the system constraints (Blanchard and Fabrycky 2010). This becomes more challenging when dealing with an

SoS, because trade-offs in an SoS often involve concessions from individual systems that have already gone through an analysis of alternatives to bring their systems into existence (OSD 2008). The trade-offs in the systems engineering process for a system can often be balanced with cost efficiency and its ability to achieve a desired measure of performance. SoS trade-offs could potentially be more complicated, as certain trade-offs may be made just to get constituent systems to buy in to the SoS. Extensive negotiations must take place so that each individual system's stakeholder feels comfortable with its role in the SoS (OSD 2008). In a directed SoS, this could take years, because each individual system would have to go through its own analysis of alternatives, followed by an analysis of alternatives for the SoS.

(7) Orchestrating SoS Upgrades

The difference between a system upgrade and an SoS upgrade can be seen by comparing the upgrade in software that occurred on the Patriot System to go from PAC-2 to PAC-3 missiles as opposed to a software upgrade for the complete BMDS. Because SoS upgrades are very large undertakings, the SoS Engineering Guide advocates upgrading in increments (OSD 2008). Orchestrating SoS upgrades must take all of the other six core elements into consideration in order to be executed successfully. A system mapping to capability requirements should be carefully planned, resourced, and modeled to ensure that the SoS upgrade is executed in the most efficient manner that maximizes performance.

The SoS systems engineering process is depicted in Figure 5. Notable in this diagram is that the SoS process assumes that each individual system acquisition is executed using the systems engineering process (OSD 2008).

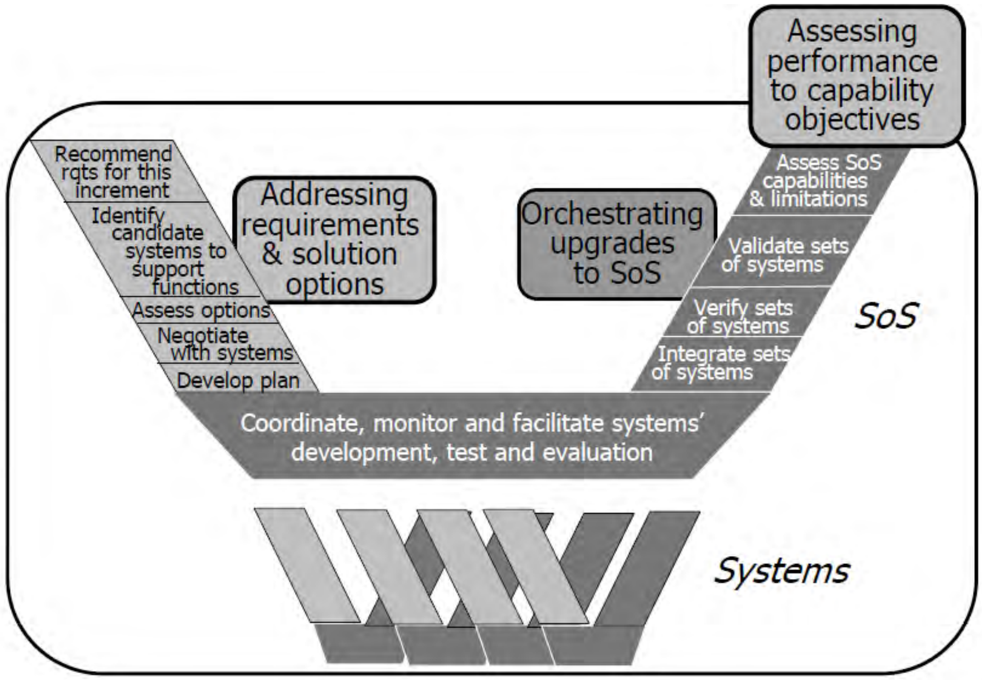

Figure 5. SoS Engineering Processes (from OSD 2008)

The following chapters discuss past and present Army programs through the lens of these core elements to determine the best practices for an SoS approach to all existing and future Army programs as well as if implemented, how the SoS approach should be executed.

III. ARMY SYSTEM OF SYSTEMS

This chapter will examine three case studies of previous Army SoS acquisitions, the Counter Rocket Artillery Mortar System (C-RAM), the Army Battle Command System (ABCS), and the Future Combat System (FCS). Using the core elements from SoS engineering, lessons learned will be obtained in order to make recommendations for process and organizational changes for current and future Army SoS acquisitions.

A. COUNTER ROCKET ARTILLERY MORTAR SYSTEM

The C-RAM is an SoS built-in response to the indirect fire that was impacting operations in Iraq and Afghanistan. The SoS was built in 2004 based on an Operational Need Statement from Multinational Forces in Iraq. Leaders expressed a need for early identification and destruction of incoming mortars in order to reduce the adverse effects of operations in the Area of Responsibility (AOR) (Whaley and Stewart 2014). The C-RAM was built largely from existing systems from different Army branches as well as different services. The Forward Area Air Defense Command and Control (FAAD C2) is the main command and control system for the C-RAM. It uses hardware and software to provide an air picture for the operator (Program Executive Officer Missiles & Space—Anywhere—All the Time [PEO] 2015). It is used by divisional or short range air defense units to support the Army air defense mission by providing an air picture to complement other Army air defense systems, such as Patriot and THAAD. The C-RAM also uses the Air and Missile Defense Planning and Control System (AMDPCS) that provides an air picture for all echelons of air defense, the Air and Missile Defense Workstation (AMDWS) that initially was created as the Command and Control center for PATRIOT, Systems. The C-RAM provides an air picture for short range ballistic weapons, and also can simulate engagements on the battlefield based on a threat profile and friendly capabilities (PEO 2015). The C-RAM SoS also has early warning and cueing capabilities. These cueing capabilities are provided by a wireless system called Warn, which uses wireless technology to integrate with existing security systems and provide audio and visual warning in the AOR. The radar that provides the air picture for the C-RAM is the

AN/TPQ 36 and 37 radars (PEO 2015). These radars initially were created to support the field artillery mission of detecting short- and long-range rockets and mortars. They currently provide detection capability for the C-RAM (Higgins 2007). The weapon system for the C-RAM is a version almost identical to the Navy MK 15 Phalanx close-in weapon system (CWIS) used as the final layer of defense for ships. Adjustments had to be made to convert the ship-based platform into a land-based platform (PEO 2015). The diagram in Figure 7 illustrates the SoS architecture for the C-RAM.

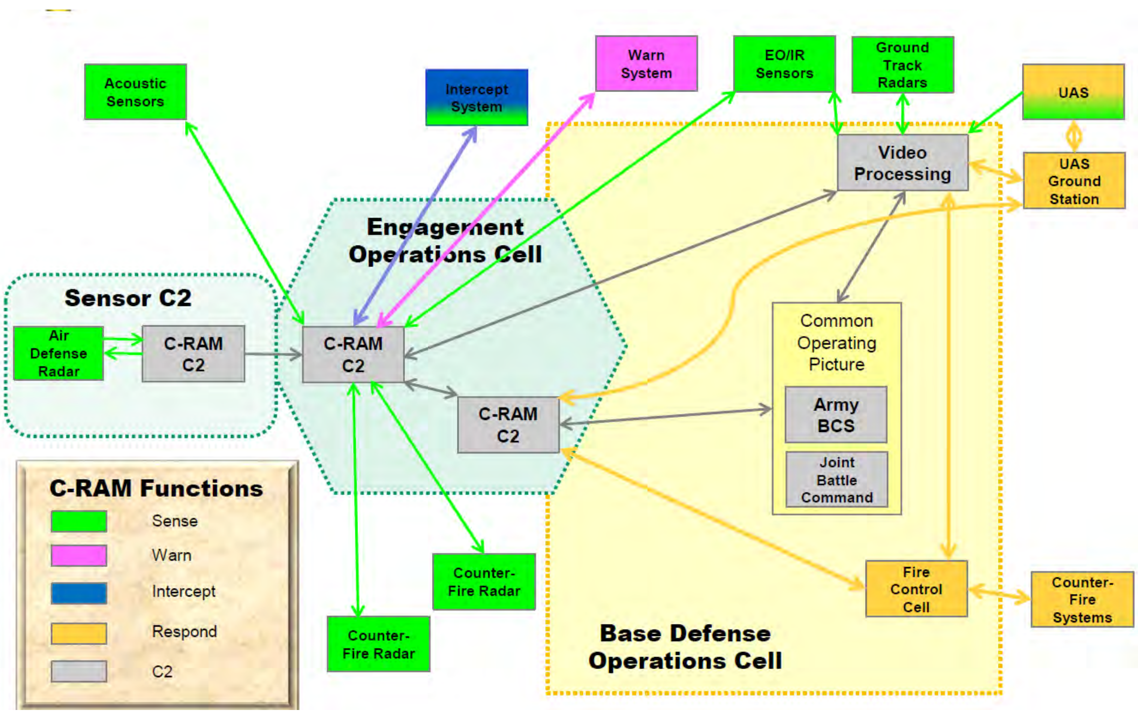

Figure 6. C-RAM SoS Architecture (from Bloodsworth 2010)

(1) Acquisition Process

One of the notable accomplishments about the C-RAM project was that it took less than fifteen months to go from operational need to an initial operating system (Archer 2014). The unclassified C-RAM performance ranges from a 60–70 percent probability of intercept against incoming mortars (Global Security 2015). In addition, during OIF, the C-RAM provided early warning for over 1,500 incoming rounds (Army C-RAM Intercepts 100th Mortar Bomb in Iraq 2009). Archer states the "C-RAM leveraged existing technologies within the DOD and private sector to curtail the typical system-of-systems acquisition timeframe of 10–20 years" (2014, 32). Using the core elements of SE SoS, the thesis examines the C-RAM acquisition process in the next section.

(2) Translating Capability Objectives

Translating capability objectives must start with a broad need statement especially for SoS. The C-RAM is in the category of an acknowledged SoS. The Operational Need Statement called for "an indirect-fire intercept capability" (Corbett 2012, 47) during Operation Iraqi freedom. The need statement meets the criteria for a broad SoS capability need because it is general enough to facilitate an analysis of alternatives and also effectively describes the need for personnel in theater. The fact that the threat was immediate, instead of the forecasted threats that usually drive the acquisition process, provided context for the designers and builders to create a system to meet the users' needs.

(3) Understanding Systems and Relationships

The C-RAM consists of the land-based Phalanx weapon system for intercept purposes, the Forward Area Air Defense Command and Control (FAAD C2) and Air and Missile Defense Workstation (AMDWS) for command and control functions. The Lightweight Counter Mortar and Firefinder radars from the Field Artillery branch were used as sensors, and the Warn system used for early warning. One of the strengths of the C-RAM acquisition process was the ability to understand systems and relationships. One of the reasons for this is that the C-RAM started with a Joint Urgent Operational Needs Statement (JUONS). The JUONS was created in 2004 to facilitate a more streamlined acquisition process to counter urgent threats. The JUONS ensured that multiple perspectives examined these needs (Whaley and Stewart 2014).

Another demonstration of the decision authority demonstrating an understanding of systems and relationships in the C-RAM was their ability to decompose the problem statement effectively. This was evident in the way C-RAM acquisition was task organized. For example, the Field Artillery branch of the U.S. Army was the first branch involved with the C-RAM because the Field Artillery already had systems with the ability to detect short- and long-range mortars. Although the field artillery could identify mortar locations, they did not have C2 systems capable of simultaneously providing intelligence, and maintain a common operating air picture in a joint environment. (Higgins 2007). This is where the Army Air Defense came into play. The decision makers demonstrated understanding that the FAAD C2 and AMDWS provided the C2 needed for the C-RAMs operational environment. The decision maker understood that that neither the Air Defense nor Field artillery had the offensive capability to intercept incoming mortars. This led to the inclusion of the land-based Phalanx weapon system that was used in the Navy at sea. The Navy demonstrated the capability to defend against incoming mortars with the CWIS, so it made sense to utilize the Navy's experience in developing an intercept capability for the C-RAM (PEO 2015). The warning capability was given to contractors. Clearly, decision makers understood the relationships between the C-RAM constituent systems, and demonstrated a great understanding of the C-RAMs operational requirements to effectively decompose the problem to incorporate existing systems from different branches of the Army and Navy.

(4) Assessing Performance to Capability Objectives

Assessing the performance to capability objectives usually happens during operational testing. All of the subordinate systems were available to conduct a full operational test during the C-RAM acquisition. This is a rare occurrence in SoS because, as described in Chapter II of this study, testing all constituent systems simultaneously is challenging. Testing systems individually is different from testing the SoS because interoperability testing is a significant undertaking for an SoS. Assessing the performance to capability objectives for this SoS was relatively straightforward in part because the need statement was clearly defined. Additionally, similar capability objectives are required for the tracking, detection, and interception of any incoming target, and the DOD had extensive experience meeting these objectives from prior air and missile defense systems. Operational testing was conducted in Yuma, AZ, by an Air Defense unit. The C-RAM SoS represented systems from different branches of the military, but the users and testers were all in the Air Defense branch. A critical part of operational testing is for users with contextual knowledge of the system to provide feedback on system performance. Given that the concept of joint operations was still relatively new to the DOD, there was little initial effort to involve other branches and services in the operational testing. As a result, an assessment of performance to capability objectives was successful but could have been enhanced if more effort was placed on incorporating users from different branches of the Army.

(5) Developing and Evolving an SoS Architecture

The development of the initial SoS architecture was facilitated through the close relationship with acquisition decision-makers and the Army testing agency. C-RAM did not introduce any new capabilities without going through Army Test and Evaluation Command (ATEC). Effective communication between the PMs also facilitated an evolving architecture for the C-RAM. Although it was developed in a short period of time, the changes that occurred were smooth due to the communication between PMs and communication with the testing agency. During a test and evaluation (T&E) briefing, Bloodsworth (2009) states that, “Multiple changes were required in the C-RAM’s program of record (POR) component system; All such changes were agreed to between the C-RAM and POR PMs” (11). This statement speaks to the ability of C-RAM stakeholders to develop and evolve the existing SoS architecture.

Along with developing an SoS architecture, it is always important to have a good understanding of the concept of operations. Although the C-RAM was effective in OIF, there were issues with the collateral damage risks that occurred when using the system operationally. It is likely that these issues may have been avoided if a thorough concept of operations was generated prior to the C-RAMs deployment. In a general sense, operators deployed knowing their mission was to warn, detect, and intercept incoming mortars; however, extensive analysis on the effects of deploying the system to theater did not occur. One of the characteristics of the C-RAM is that it fires many rounds at a single mortar. In a counterinsurgency environment where one of the main goals is to protect the civilian population, protecting civilians is challenging when the C-RAM is firing 180–200 rounds at a mortar. In theory, the shells that do not engage the mortar are supposed to self-destruct in the air; however, there is always a chance that shrapnel from the mortars will endanger civilians. As stated in Higgins' study, "At the tactical level, the clearing of fires before the gun could engage a hostile round resulted in failed interceptions" (2007, 27). The failed interceptions were a result of the Army not receiving clearance in time to fire at the incoming mortars. This collateral damage issue might have been understood in greater detail if a through concept of operations had been in place. A thorough concept of operations is needed in order for the system architecture to evolve with changing environments.

(6) Monitoring and Assessing Changes

The C-RAM subordinate systems have had several changes to the sensor, command and control, and intercept systems (Corbett 2012). These changes were mostly software changes that did not have a detrimental effect on interoperability for the C-RAM system. However, training for personnel that were manning the system was difficult because operators could not keep up with developments in the individual systems (Corbett 2012). Army short-range air defense units took on the majority of responsibility for the C-RAM mission. Keeping up to date on systems outside of the Air Defense specific systems proved to be challenging. Personnel were not familiar with software upgrades and had difficulty acquiring necessary parts for the system. These challenges are described in the air defense and field artillery Fires bulletin, which states, "Logistics for the C-RAM program has grown in fits and starts along the materiel domain path where, initially it was not keeping pace with the rapid, spiral development of the sensor, shooter, and command and control equipment in the acquisition process" (Corbett 2012, 53). This speaks to the logistical challenges that existed during subordinate systems' evolution. A mitigation that is currently in place is the transforming of two short-range Air Defense units completely into C-RAM units. This transformation will facilitate training and build training depth for the C-RAM system. The transformation will also help with the logistical challenges, because dedicated users will be continuously maintaining the system and becoming familiar with needed parts.

(7) Addressing Requirements and Solution Options

The C-RAM system addresses the total threat of incoming mortars by providing early detection, tracking ability, and intercept capability. As a result, the C-RAM system is flexible enough to address a number of requirements in varying operational environments. The stakeholders' ability to understand the requirements led to solutions that met the operational needs of the system. As pointed out previously, there were issues with the CONOPS initially because intercepting mortars requires air and ground clearance, which is not always practical, especially in urban environments. However, the flexibility of the SoS found workable solutions to the CONOPS issue. For example, several Forward Operating Bases (FOBs) use part of the C-RAM strictly for its early warning capability. This capability allows personnel time to find cover during an incoming indirect fire attack. Future iterations involve replacing the Phalanx with a high energy laser to reduce or eliminate the requirement for ground clearance. Short-term developments for the C-RAM focus on addressing performance requirements and solutions through software changes, and increasing the intercept systems probability of kill. In the meantime, the flexibility of the C-RAM in its current state allows the system to provide adequate solutions in a variety of operational environments.

(8) Orchestrating Upgrades to SoS

One of the challenges of the C-RAM SoS has to do with the funding of the SoS. Each independent system has its own program, which means that each system has its own line of funding or POR (Whaley and Stewart 2014). One of the most significant upgrades proposed for the C-RAM system is upgrading the intercept system from a shell- and missile-based system to a laser-based system. This will improve accuracy and reduce the threat the current system has on personnel, especially in populated areas. Funding still has to be captured in order to responsibly manage the upgrades. As Archer states, "It is difficult to quantify the amount of funding that has been directed to the C-RAM program. Funding has come from multiple budgets" (2012, 33). The establishment of a program director responsible for the SoS, as well as the constituent systems, is currently leading efforts to codify the funding for the C-RAM program.

B. ARMY BATTLE COMMAND SYSTEM

The Army Battle Command System (ABCS) is an SoS designed to consolidate the U.S. Army's command and control platforms. In addition, ABCS facilitates the decision-maker's ability to execute command and control responsibilities, such as planning operations orders, disseminating information, and assessing situations. ABCS facilitates bottom-up feedback as well. This can all be done without individuals being physically located at the same place. The constituent systems that make up the SoS are as follows:

- Global Command and Control System (GCCS): The GCCS system is the link between Army tactical units and the joint environment. It provides the common operating picture link to joint platform (ABCS Smart book 2001).

- Distributed Common Ground Station-Army (DCGS-A): The DCGS-A is a comprehensive intelligence information source for the Army and joint force. It provides surveillance, a variety of map overlays with imagery, and terrain analysis. It also provides access to open source material on the Internet (Department of the Army 2009). Other systems in the ABCS that provide intelligence data are the digital topographic support system and the integrated meteorological system.

- Battle Command Sustainment Support System (BCS3): The BCS3 is used by logisticians to provide real-time logistical information and facilitates the supply chain process with a common operating picture for logistics at different operational levels. (Department of the Army 2009).

- Tactical Airspace Integration System (TAIS): The TAIS provides situational awareness for airspace controllers at different levels. It also facilitates the deconfliction of civilian and military assets, and provides a common operating picture for Army aviation assets and joint military assets in the airspace (Department of the Army 2009).

- Air and Missile Defense Workstation (AMDWS) and the Advanced Field Artillery Tactical Data System (AFATDS): These systems are the C2 nodes for the Air Defense and Field Artillery branches, respectively (Department of the Army 2009).

- Force XXI Battle Command Brigade and Below (FBCB2): The FBCB2 is the main C2 platform for Army units Brigade level and below. It provides friendly unit locations and facilitates the dissemination of operations orders. It is the link between the brigade units and the higher headquarters (Department of the Army 2009).

- Battle Command Common Services (BCCS): This is the server that links the constituent systems of the ABCS and provides interoperability (Department of the Army 2009).

The diagram in Figure 7 depicts the ABCS and its constituent systems.

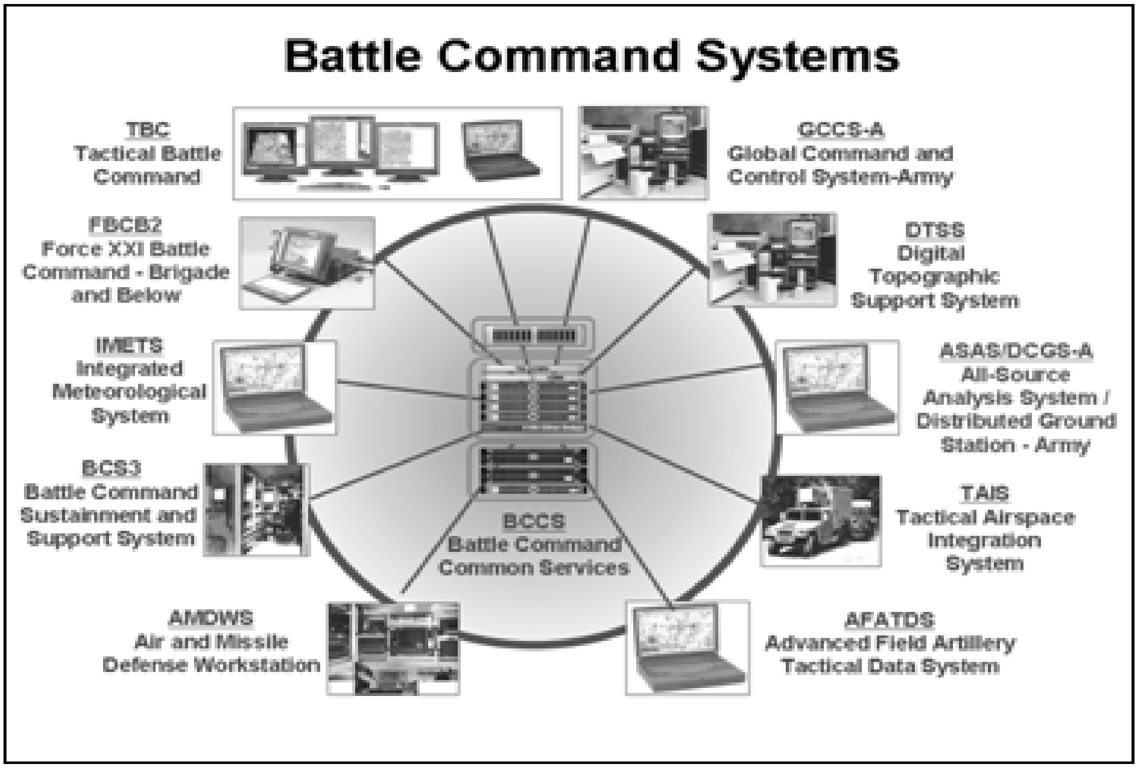

Figure 7. Army Battle Command Systems Architecture (from DOT&E 2001)

(1) Acquisition Process

Similar to the C-RAM, the ABCS was built using existing systems. It also was an acknowledged SoS because the platforms were already fielded. One major difference in the acquisition process was that the ABCS process evolved from an operational requirements document developed in 1995 (Department of the Army 1994). However, the ABCS was not fielded as an SoS until 2005. Prior to this period, the ABCS term was used to refer to the collection of systems but lacked the integration of an SoS. The operations requirements document was part of the Army digitization plan created in 1995 (Department of the Army 1994). The Army digitization plan included the ABCS common operating environment/common applications requirements document (Department of the Army 1994). This document called for the "migration of current separate Army command and control component systems into one integrated system" (Department of the Army 1994, 3). It called for not only vertical integration, which would go from the higher headquarters down to the lowest level, but also horizontal integration, which allowed everyone in the network to see the commands instantaneously (Department of the Army 1994).

(2) Translating Capability Objectives into SoS Requirements

The desire to integrate existing stove-piped Army command and control systems into a single integrated system drove the creation of the SoS (Department of the Army 1994). Around 1995, there were several individual systems such as the FBCB2 and Blue Force Tracker (BFT) being developed independently. The Program Executive Officer Command, Control, and Communications Tactical (PEO C3T) attempted to create an SoS from these evolving systems (Greene and Mendoza 2005). This broad task was a straightforward capability need, and the integration was all network-centric, as opposed to an SoS for which physical integration was necessary. The challenge that stemmed from translating capability objectives into requirements was addressed by the Chief of Staff of the Army (CSA) of the Army in 2003. He realized that most of the individual C2 platforms being developed were based on bottom-up information (Greene and Mendoza 2005). Many of the individual systems, such as the FBCB2, were created to pull information from subordinate units. In the case of the FBCB2, subordinate units would usually communicate their location through radio, and a member of the Army staff would update their location on the map. The CSA realized the need for a top-down approach to the ABCS acquisition. This would mean that requirements would be looked at from the service and joint levels (Greene and Mendoza 2005). This top-down approach helped to lay the groundwork for the SoS architecture that currently exists.

(3) Understanding the Constituent Systems and Their Relationships

One of the positive things about the initial bottom-up development of ABCS constituent systems was that it allowed users at the lowest level to become familiar with the system. This familiarity led to increased and valuable user feedback when the individual systems were being developed. As stated in the article by Greene and Mendoza, "Development of ABCS 6.4 is proceeding from the warfighter's perspective and incorporates user feedback that defines 69 operational good enough requirements" (2005, 201). Incorporating users at the lowest level created a broad knowledge base of individuals on their respective systems, which facilitated the understanding of the relationship between systems. Another point is that all of the subordinate systems were specific to a particular Army branch. For example, the AMDWS was created based on the tactical needs of the Air Defense branch; the AFATDS was based on the tactical needs of the field artillery. The Army at the time had a lot of experience with combined operations from exercises and previous conflicts, so understanding the relationships between platforms was easier for this reason as well.

(4) Assessing Performance to Capability Objectives

As previously mentioned, the incorporation of user feedback was a significant factor in the ABCS acquisition. This as well as testing had a positive impact on assessing the ABCS performance. Additionally, in 2003, the CSA established metrics for where the ABCS should focus their efforts. These metrics centered on the following areas:

- Friendly Locations
- Current Enemy Situation
- Running Estimate
- Graphic Control Measures
- Fragmentary Orders
- Commanders Situation Report
- Fire Support Coordination Measures/Capabilities Overlay
- Joint and Coalition Interoperability

(Greene and Mendoza 2005)

There was a lot of information contained in all of these systems. When the CSA focused on these areas for performance, it made it a lot easier to assess the performance against capability objectives. The CSA wanted to establish a system that was "good enough" for fielding (Greene and Mendoza 2005).

(5) Developing and Evolving an SoS Architecture

Developing the SoS architecture for the ABCS was challenging for the Army. Individual systems were already fielded in the respective Army branches. Additionally, Army doctrine such as the Military Decision-Making Process (MDMP) required Army staff at high levels to conceptually integrate information from different Army branches (Frambes 2005). Conceptually, most of the analysis required to develop an SoS structure had already been completed. However, the transition from a stovepipe process to an SoS process created challenges when trying to create a networked architecture. As stated by Greene and Mendoza, "ABCS 6.4 good enough was moving from a loosely coupled architecture to a tightly coupled SOS architecture, but too often, issues and problems were perceived as individual software releases geared to stovepipe solutions" (2005, 206). This challenge was mitigated by the establishment of several integrated product teams (IPTs) that focused on SoS development in several different areas.

(6) Monitoring and Assessing Changes

Once the ABCS was established as an SoS, individual systems, such as the Command Post of the Future (CPOF), were created to be interoperable with the ABCS. Even though the CPOF was developed as an individual system, one of the requirements for it to become a program of record was to establish interoperability with the ABCS (Greene 2010). Other systems, such as the DCGS-A, which is the intelligence tool that evolved from the All Source Analysis System (ASAS), followed a similar pattern. The IPTs were also instrumental in monitoring and assessing system changes. They ensured that major software upgrades for the ABCS were coordinated through individual systems. The ABCS has transitioned to a Publish and Subscribe Server (PASS) system and made more than four major software updates without degrading the individual systems' capabilities (Greene 2010).

(7) Addressing Requirements and Solution Options

The ABCS had the benefit of operational testing at the SoS level. As shown earlier, SoS testing is extremely difficult due to individual systems being in different levels of maturity and different stages of the acquisition process. ABCS SoS testing led to the identification of requirements outside the scope of individual systems, and proposed solution options for the SoS as a whole. As stated in the Directorate of Operational Test and Evaluation (DOT&E) pamphlet, "The ABCS SoS assessment contributed valuable insights to the evaluations of the individual acquisition programs. By taking a more holistic approach, the assessment identified significant issues beyond the scope of a single program manager's responsibility" (2005, 46). This suggests that the SoS testing addressed SoS requirements and also addressed individual system issues to help meet individual system requirements. The results of this testing led to proposed solutions that addressed SoSs as well as individual system requirements. It also underscored the fact that with SoS, testing of the entire SoS produces results that cannot be obtained from testing systems individually. These recommendations included an improved network architecture, increased network security, and funding for collective training (DOT&E Army Programs 2005, 46). Testing also led to the development of the central information server that exists with the system today.

(8) Orchestrating Upgrades to SoS

In 2004, the Army decided to change the direction of the ABCS development from a bottom-up approach to a top-down approach. During this time the Army also refocused and reprioritized the desired capabilities for the ABCS. The PEO organized the Army stakeholders into several IPTs and established what he termed as "good enough" requirements for the IPTs to achieve in the 6.4 version of ABCS (Greene and Mendoza 2005, 206). The good enough requirements were important because they provided a capability while acknowledging that the SoS would not be fully mature with version 6.4. This iterative approach to development encourages developers to design systems and architectures that could be upgraded easily in the future without major changes to the system architecture. Since 2005, the ABCS has successfully added new systems, such as the CPOF, and the ABCS is becoming part of a broader Army initiative called Capability

Set 13 (CS-13). Capability Set 13 and those that follow will significantly increase the network capacity of the ABCS, and add platforms for the dismounted soldier to access information provided by the ABCS. This ability to orchestrate upgrades was enhanced by the decision to incrementally field systems while keeping upgrades in mind.

C. FUTURE COMBAT SYSTEMS

The Army Future Combat Systems (FCS) represents the biggest SoS undertaking that the Army has ever attempted. The idea started in 1999 and large portions of the program were cancelled by 2009. The Army FCS was a directed SoS intended to completely change the way the Army fought wars. The idea originated from then Army Chief of Staff General Shinseki. His intent was to take the existing Army division structure and transform it to a lighter, more mobile force that could deploy a division-sized unit in five days (Feickert 2009). The SoS would take existing Army platforms and integrate these platforms into a large network that would be consistent throughout the whole Army. The FCS was the largest acquisition project the Army ever attempted in terms of cost. It was also the first time that the Army initiated an SoS; usually the Army would identify a capability gap and build a system or combine systems to meet this capability gap. The FCS was the first directed SoS for the Army. The FCS consisted of four systems: the manned FCS ground systems, unmanned air vehicles, unmanned ground vehicles, and sensors/weapons. Table 3 describes the typical equipment that would be organic to an FCS Brigade.

Table 3. Army FCS Brigade Equipment List (from Congressional Budget Office 2006, 30)

Planned New Components for an FCS-Equipped Brigade

	Quantity[a]
Manned Systems	
Mounted Combat System	60
Infantry Carrier Vehicle	102
Command-and-Control Vehicle	49
Reconnaissance and Surveillance Vehicle	30
Non-Line-of-Sight Mortar	24
Non-Line-of-Sight Cannon	18
Medical Vehicle	29
Recovery and Maintenance Vehicle	10
Unmanned Ground Vehicles	
Armed Robotic Vehicle-Assault	18
Armed Robotic Vehicle-Reconnaissance, Surveillance, and Target Acquisition	27
Armed Robotic Vehicle-Assault (Light)	18
Multifunctional Utility, Logistics, and Equipment Vehicle	90
Small Unmanned Ground Vehicle	81
Unmanned Aerial Vehicles (Launch and Control Units/Aircraft)	
Class I	54/108
Class II	36/36
Class III	12/48
Class IVa	2/8
Class IVb	8/16
Other	
Unattended Ground Sensors	136
Non-Line-of-Sight Launch System	60
Intelligent Munitions System	30 or 88[b]

All of the subsystems in the manned systems category were designed to be lighter and faster versions of Army legacy systems. For example, the mounted combat system (MCS) was intended to be a lighter and faster version of the Abrams tank with equivalent firepower (Congressional Budget Office [CBO] 2006). The infantry carrier vehicle (ICV) would replace the Bradley fighting vehicle and M113 personnel carriers. The ICV would also be lighter and faster than the Bradley with increased firepower. Similarly, the non-line of sight mortar and cannon (NLOS-M/C) would replace the M-113 and M109 howitzer, respectively (CBO 2006). The recovery and maintenance vehicle would replace the M88 recovery vehicle (CBO 2006). The unmanned ground vehicle system was split into four classes, and each class would be designed to support a specific Army force size. The class I UAVs would be designed for the individual soldier, the class II UAVs would support a company-sized element, the class III UAVs would support a battalion-sized element, and the class IV UAVs would support a brigade-sized element (CBO 2006). The unmanned aerial UAVs were divided into a similar class structure as the unmanned ground system, and they supported the same-sized unit. The unmanned sensor and fire systems would be designed to increase intelligence and initiate fires via remote control. Figure 8 shows the FCS SoS and its constituent systems.

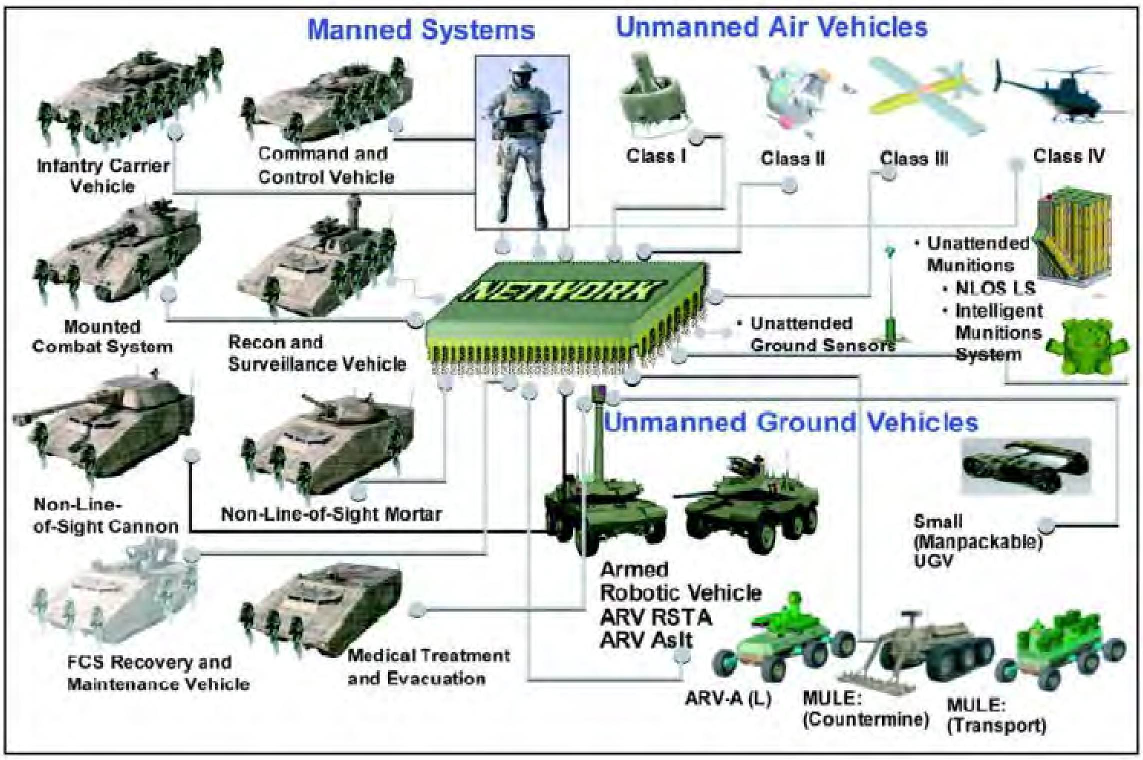

Figure 8. Army FCS SoS (from Global Security.Org 2011)

(1) FCS Acquisition

The FCS acquisition plan was a long-term but aggressive plan to get the entire Army transformed by the year 2032 (Feickert 2009). The plan called for seventy-one Army Brigades, each having eighteen systems fielded by 2032. It was soon realized that this schedule could not be maintained and several changes occurred, including reducing the number of simultaneously fielded systems from eighteen to fourteen, and program restructuring that occurred in 2004 (CBO 2006). This also reduced the number of systems that were simultaneously fielded. There were several contractors on the FCS project as well. DARPA was one of the primary contractors, and they worked with the lead system integrator (LSI) team of Boeing and SAIC (Gansler 2009). Much of the work was subcontracted as well. This proved to be a challenge when trying to test and integrate systems at the SoS level. Further, the cost of the FCS was intended to be roughly $200 billion for research and development and procurement (CBO 2006). However, during the program's first four years, the program experienced cost growth between sixty-nine to 100 billion dollars more than initially estimated. The increasing cost growth without substantial, tangible results led to the program's cancellation in 2009 (Cordesman 2009). Looking at the core concepts of SoS engineering will provide some insights into potential reasons for why the program was canceled.

(2) Translating Capability Objectives

The FCS program had a broad capability to make the Army "more responsive, lethal, versatile, survivable, and sustainable" (Pernin et al 2012, 9). Although SoS capability objectives must be broad enough to generate SoS requirements, the capability objectives described for the FCS, such as lethality and versatility, were broad enough to generate multiple SoSs. The FCS was expected to address all of these warfighting functions simultaneously. Although the initial objectives were broad, when they were translated into requirements, they became very specific down to the system level. There must be a delicate balance between requirements that are specific enough to meet the objectives, but not so specific that they impact the generation of alternatives for the SoS. In the case of the FCS, requirements significantly reduced the design space for the SoS. An example of this can be seen from the C-130 requirement. All FCS systems were required to be C-130 deployable. This was considered a non-negotiable requirement (Pernin et al 2012). As a result, this requirement would impact the size and weight of all the platforms being designed. Although the increase in time and money was not quantified, this requirement likely resulted in unnecessary additional costs and time; the Army has other air assets available that could be used to air transport the FCS. As the

FCS progressed, the restrictive nature of the C-130 requirement became apparent. Efforts to try and change this requirement would prove difficult, as evidenced by the RAND report which states that removing the C-130 requirement "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" (Pernin et al 2012, 58). The requirement was eventually relaxed a few years later.

(3) Understanding Systems and Relationships

The FCS platforms were primarily based on existing systems. For example, the MCS was centered on maneuver vehicles such as the Abram and Bradley vehicles. The unmanned aerial and ground vehicles were designed to support specific force sizes in the Army. As a result, clear system boundaries were established for each of the platforms, and their relationships with other systems were also clearly understood because legacy versions of the platforms already existed, and new platforms fell within the boundaries of existing Army force structure. For example, there were unmanned vehicles designed to support the individual, company, battalion, and brigade levels. The challenge arose when trying to understand network system boundaries. The FCS was required to be completely interoperable (Davis and Bagwell 2004). Each platform would have the capability to pass information to other platforms. The approach to accomplish this networked activity was to build platforms only after they had demonstrated the ability to communicate with existing platforms. Evidence of the interoperability requirement is illustrated in an SoS integration report, which states: "Specific FCS systems will be procured only after four dimensions of integration are demonstrated—vertical, horizontal, performance and interoperable" (Davis and Bagwell 2004, 17). The vertical and horizontal dimensions mirror the Army's expectations for communication on the battlefield. For example, a brigade level system must be able to communicate with its subordinate battalion level systems. Horizontal communications refer to systems at the battalion level being able to communicate with other battalion level systems. Performance and interoperability are based on metrics defined in the requirements. The four-dimension integration proved to be challenging because there were several different contractors, such as Boeing, General Dynamics, DARPA, and SAIC, working on the platforms. This approach to integrating the platforms did not demonstrate a true understanding of systems and boundaries because each of these contractors has its own agenda and its own information which it may be unwilling to share. The different contractors involved that were supposed to collaborate did not collaborate enough to build the type of SoS that the Army envisioned.

(4) Assessing Performance to Capability Objectives

Assessing the performance to capability objectives was challenging because the FCS was such a massive project (Pernin et al 2012). The FCS was designed to address future capabilities by upgrading old systems. As a result, several assumptions were necessary to build the system. As stated in the Pernin RAND study, one assumption that had a profound impact on assessing performance to capability was that the U.S. Army would be engaged in state-to-state conflicts. While there was some insurgency in one particular scenario, most of the scenarios focused on state-to-state actors (Pernin et al 2012). Another assumption was that the capabilities for conventional warfare would be sufficient to combat insurgent warfare. The focus on state-to-state actors framed the context for which the SoS was evaluated against capabilities. A few years later, in 2004 and beyond when the United States faced insurgencies in both Afghanistan and Iraq, the FCS was disconnected with the current threat. The FCS depended almost completely on simulation testing to assess performance to capabilities (Pernin et al 2012). While simulation is a cost-effective tool, it does not always yield accurate results on how the system will perform, because models are only as good as their inputs and the validity of the model assumptions. Assessing the performance was shaped by assumptions that were not necessarily true. As a result, the FCS program conducted testing and evaluation based on invalid assumptions, which led to an inaccurate assessment of performance to capability objectives.

(5) Developing and Evolving an SoS Architecture

Individual system requirements for FCS systems were conducted in conjunction with SoS system requirements. This dual development made it difficult to establish a system architecture at the SoS level. As alluded to in the RAND study, systems engineering was being conducted at the system level. During this process, trade-offs were also conducted at the system level without taking SoS level requirements into consideration (Pernin 2012). This suggests that the individual systems had a significant impact on the intended SoS architecture. The individual systems were so complex that by the time the systems were considered in the context of an SoS, the trade-offs would be costly in performance, schedule, or dollars to make any changes that facilitated the SoS development. There is no evidence suggesting that any detailed SoS architecture was conducted early in the SoS development. Ideally, for a directed SoS, an SoS architecture should be completed first so that individual systems can maintain an SoS perspective when designing and building individual systems. This was not the case for the FCS. Without a baseline architecture, individual systems were designed independently and then expected to integrate with existing systems. This type of approach is more appropriate for an acknowledged SoS system. In an acknowledged SoS, the platforms already exist, and therefore a bottom-up approach is necessary. In an acknowledged SoS, most individuals are familiar with the existing systems so it is easier to suggest trade-offs and come up with ways for systems to be interoperable. In the case of the FCS, the SoS was directed but approached from the bottom up as if the systems were already in place. Further evidence of the issues with this bottom-up approach is described in the RAND study, which states:

> 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. (Pernin et al 2012, 93)

(6) Monitoring and Assessing Changes

As previously stated, the acquisition budget grew by almost $100 billion over three years. During that time period and a couple of years prior, several changes took place in the FCS program that was not accurately assessed. According to a Center for Strategic and International Studies (CSIS) report, budget constraints led to the reduction of four FCS constituent systems. Although it was intended to reduce cost, there was no change in the budget to reflect this reduction (Cordesman 2009). One of the characteristic traits of the FCS acquisition was that developers did not seem to understand how external

SoS changes such as program cuts would impact the system. Some of this stemmed from not having an SoS architecture, and part of it stemmed from the lack of understanding of how new systems would be interoperable with one another. Requirements changes also were difficult to assess. As each system developed independently with its own requirements, when changes were necessary to accommodate the SoS, they often occurred slowly and sometimes at a cost (Cordesman 2009). These costs led to system cost and schedule growth without any significant system development progress.

In the early stages of the Iraq and Afghanistan war, there was a notable difference in the insurgency the coalition force was fighting and the type of operations the FCS was being designed to accomplish. To mitigate this discrepancy, the FCS changed the acquisition strategy to adapt to the changing environment in these theaters. These "spin-out" technologies would go directly to the soldiers on the ground and have a separate development schedule than the FCS (Pernin et al. 2012). These spin outs led to the development of some UAVs and unmanned ground systems. However, as the RAND study points out, these spin outs were not part of the original plan and added to the cost, and delayed the schedule (Pernin et al 2012). The long-term FCS project was transforming into both a long- and short-term project without the staff to support such a change. As stated in the RAND study, "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" (Pernin et al 2012, 38).

(7) Addressing SoS Requirements and Solution Options

The issue of requirements at the system level and the SoS level has been addressed extensively in this paper. These issues stemmed from the development of individual systems without an SoS perspective. Another aspect of the requirements was the validation process for the FCS program. Due to General Shinseki's eagerness to begin fielding the system as quickly as possible, the FCS program did not go through the rigorous requirements validation programs that normal acquisition programs go through (Bradford 2011). The FCS bypassed key senior Army leaders who may have been able to add valuable input to the requirement generation process. As a result, several changes had to occur after time was spent building to requirements that had not been properly vetted.

The FCS was intended to move the Army into the future. As stated earlier, most of the requirements were geared toward operating the FCS in a conventional war. However, during development an unconventional war was occurring, which caused the FCS to change its acquisition strategy to accommodate the ongoing conflict. It is difficult to find solution options if the problem keeps changing. In the case of the FCS, the problem the FCS was originally optimized to address changed significantly. This often leads to scope creep and a suboptimal solution to multiple problems. The FCS was heading down that road before it was cancelled in 2009.

(8) Orchestrating SoS Upgrades

In 2009, then Secretary of Defense Robert Gates made the decision to cancel the FCS program. Although the FCS as an SoS never came to fruition, the FCS efforts led to successful spin-off systems. For example, a lot of the technology used for the Maneuver control subsystem was used to develop the Army's current Ground Combat Systems (GCS) (Pernin et al 2012). Further, much of the technology used to develop unmanned ground and air vehicles was salvaged and fielded in places like Iraq and Afghanistan. Additionally, on a smaller scale some of the network architecture was used for future systems. Other potential spinoffs likely did not take place due to the Army having to spend nearly one billion dollars to cancel existing contracts.

D. SUMMARY OF CASE STUDY LESSONS LEARNED

The following lessons learned have been obtained from the three case studies. These lessons learned will be used in Chapters IV and V to recommend process and organizational changes respectively.

(1) Lesson #1: Leverage the JUONS process for urgent need SoSs.

The complexity of the acquisitions process often results in the belief that all SoS acquisitions will be complex efforts that take a significant amount of time to go through the acquisition process. From the C-RAM, one can note that an SoS acquisition does not necessarily have to be a long-term acquisition process, especially when dealing with an acknowledged SoS. The C-RAM was able to use existing platforms and provide a partial solution to the incoming mortar problem within fifteen months of the problem being identified. The process started with a JUONS that specifically addresses urgent threats. The C-RAM is an example of how this process can be leveraged for SoSs as well as individual systems. Using the JUONS process or an abbreviated acquisition process for directed SoSs is difficult, and should not be done unless absolutely necessary. The FCS illustrates an example of the potential pitfalls of abbreviating the acquisition process for a directed SoS.

(2) Lesson #2: Establishing a strong link from a needs statement to an SoS architecture to CONOPS development is essential.

The C-RAM also illustrates the importance of creating a need statement for SoS that is specific enough to meet the need, but general enough to generate enough alternatives to choose from. Additionally, the C-RAM underscored the importance of an SoS architecture that develops an OV-1 at a minimum. The OV-1 will facilitate a concept of operation for the SoS. This is important because it forces decision makers to think about how the SoS will work together, and it identifies problems in the early stages of development. The C-RAM underscored the need for a thorough logistics plan that is generated from the CONOPS. An SoS will have a lot of components, so it is important that a logistical plan is in place to carry the SoS through the life cycle of various CONOPS. Moreover, the C-RAM demonstrated the importance of setting up an architecture that facilitates upgrades. The C-RAM SoS conducted several software upgrades as well as platform upgrades without major SoS configuration changes. One must always look to future integration and interoperability requirements when establishing architecture for an SoS.

The FCS program used simulations to analyze the concept of operations. However, most of the simulations were based on conventional operations that the United States was used to fighting. A diagrammed SoS architecture, such as the SoS DODAF models, could have led to a broader view of SoS capabilities, and possibly could have placed more emphasis on unconventional wars, such as the insurgencies in Iraq and

Afghanistan. The FCS program instead made program changes after a significant amount of money was already spent.

(3) Lesson #3: Limit the scope of objectives for the SoS during a single iteration.

The FCS demonstrates the difficulty of implementing platform and network integration and interoperability in one iteration. During the FCS acquisition, platforms were built and then used to integrate with existing systems. This caused a significant delay in the development schedule. Directed SoSs should normally build the platforms during early iterations, and then use future iterations for integration and interoperability. The SoS wave model is discussed in the following chapter but one of the benefits of the SoS wave model is that it focuses on the evolution of the SoS so that iterations of development can be planned and resourced appropriately. The ABCS acquisition used a limited set of objectives for the initial SoS. Although there were many goals for the final system, the CSA focused on eight central objectives before the system was fielded. Often, a workable solution can be fielded when objectives are prioritized. This would expedite the acquisition process for SoS. Using the wave model and developing an architecture early in the acquisition process will lead to an effective balance of scope and time. Limiting the scope will enable stakeholders to field workable solutions in the short-term, while aiming to achieve optimal long-term solutions on future SoS iterations.

(4) Lesson #4: Use a bottom-up approach for an acknowledged SoS.

SE and SoS SE are both top-down processes. It is important that the SoS goals are clearly articulated at an SoS level before attempting to build an SoS. However, in an acknowledged SOS, it may be appropriate to generate requirements using a bottom-up approach for existing systems. A bottom-up approach looks at the individual system and explores relationships with other systems in order to create an SoS from existing systems. The advantage of this bottom-up process is that it can increase capabilities without initiating the JCIDS process. This bottom-up approach will lead to increased capabilities, and increased connectivity with existing systems. The ABCS used the bottom-up approach effectively during testing, and incorporated a lot of the user feedback from individual systems to generate SoS requirements.

(5) Lesson #5: Align SoS boundaries with organizational boundaries if possible.

An SoS has complex physical and virtual boundaries that could potentially lead to scope creep in the acquisition process if not understood properly. An important point when creating an SoS is to try and use existing organizational boundaries for initial SoS development. If the subordinate system boundaries correspond to an organizational boundary in the Army, such as a system that is specific to one Army branch, it will be easier to understand how systems interact with each other, because it will be similar to existing organizational boundary interactions. For example, in the ABCS, the Air Defense Artillery and Field Artillery use the AMDWS and the AFATDS, respectively. These Army branches have experience with combined arms warfare, and this combined arms experience led to a better understanding of how the ABCS constituent systems should interact at an SoS level. Using existing organizational boundaries as the basis for SoS development leads to better understanding of the interactions that must take place between the constituent systems.

(6) Lesson #6: Establish roles for IPTs and LSIs early in the acquisition process.

The ABCS proved that an IPT is essential to the SoS development process. An IPT will have the perspective to align constituent systems with the SoS vision. The LSI for the FCS was established early, but the role of the LSI in FCS was very broad, and seemed to evolve as the program developed. The IPTs and LSIs must have clearly defined roles early in the process so that they can create and maintain an SoS perspective throughout the acquisition process. Additionally, if a private company assumes the LSI or IPT role, there must be a government counterpart that sets the boundaries for these private companies. This will prevent situations that occurred during the FCS acquisition where the LSI had the authority to make major acquisition decisions without approval from the Army.

(7) Lesson #7: Require top-down management for a directed SoS.

Generating requirements for a directed SoS must be a top-down process. Requirements for the FCS initially focused on building individual systems. As the Army tried to integrate systems, it became evident that the requirements between systems were not coordinated, and this had a significant impact on SoS development. Additionally, using a bottom-up process to generate requirements when you have several different contractors working on the SoS could be problematic, because defense contractors may show limited flexibility when it comes to changing requirements to accommodate the SoS, especially if they feel a change in requirements would impact their bottom line. Therefore, it is especially important when dealing with multiple contractors to ensure that the requirements are generated from an SoS perspective. This SoS perspective will ensure that contractors building constituent systems keep the SoS at the forefront during acquisition development.

(8) Lesson #8: Develop an SoS architecture early in the acquisition process.

In addition to top-down requirements, an SoS architecture should precede a systems architecture in a directed SoS. In the case of the FCS, each individual new system was required to demonstrate interoperability with all existing FCS systems before the new system could be fielded. This resulted in individual systems spending a lot of time on integration with previous systems. An SoS architecture with a central platform, or network—such as on the ABCS—to integrate all new and existing systems could have saved a lot of time. Once a decision is made for existing systems to become an acknowledged SoS, the SoS architecture should be built, and the constituent systems must adjust their individual system architectures to meet SoS requirements.

IV. ACQUISITION PROCESS CHANGE RECOMMENDATIONS

Chapter III discussed lessons learned from previous SoS acquisitions from the Army. These lessons are used in this chapter to describe processes that the Army would need to incorporate in order to apply an SoS perspective to all existing and future Army programs. The Army, unlike some other services, does not have a service-specific guide on SoS Engineering. The Army does have an SoS Engineering and Integration Directorate, which is an organization that primarily deals with the development and implementation of Army SoS. This organization will be discussed in more detail in the next chapter, but many of the processes that this organization deals with should be applied to the current Army acquisition process to facilitate an SoS perspective.

The Army follows the DOD acquisition process, which can be seen in the diagram in Figure 9.

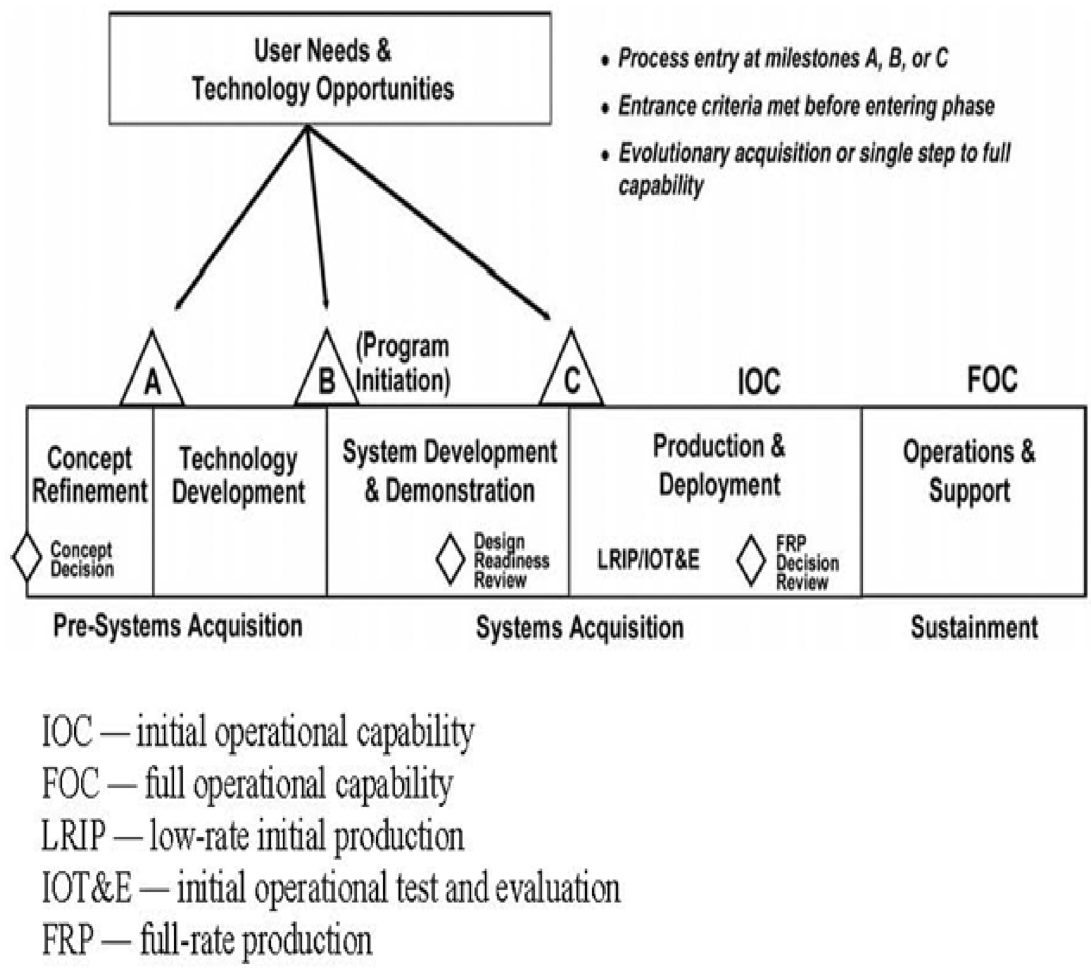

Figure 9. DOD Acquisition Process (from HQs Army 2007)

A. CURRENT ARMY ACQUISITION PROCESS

Although the processes n Figure 9 have been used to develop SoSs, the processes are primarily geared for developing individual systems. It should be noted that there are several intermediate steps involved in this acquisition process. However, this chapter will mainly focus on the processes illustrated in Figure 9. There have been several changes to the DOD acquisition process over the past several decades, with the most recent being the Weapon Systems Acquisition Reform Act of 2009. This act attempted to mitigate the frequent cost and schedule overruns that were prevalent in the Army as well as the DOD. The first step in the Army acquisition process is identifying a user need based on capability gaps. These capability gaps should be able to be traced back to the *National*

Security Strategy, *National Defense Strategy*, and the *National Military Strategy*. These gaps are identified and analyzed through the JCIDS process, which develops a capability-based assessment that stems from an integrated architecture.

B. CHANGES TO INTEGRATED ARCHITECTURE DEVELOPMENT

It is recommended that the Army better utilize DODAF for current and future Army acquisitions, and apply DODAF to document the SoS architecture.

One of the lessons described in the previous chapter is the importance of an architectural framework such as DODAF to govern the SE or SoS engineering process. Greater emphasis needs to be placed on this integrated architecture from an SoS perspective. The current requirements for an integrated architecture suggest that it facilitates SoS development. However, as pointed out in a thesis by Patrick Hoff, the integrated architecture refers to an integration of multiple perspectives (2009) as opposed to multiple platforms or networks. These integrated architectures primarily bring multiple perspectives to a single system rather than an SoS. Evidence of the single system emphasis can be seen by examining the number of individual programs that have been initiated by the Army as opposed to an SoS.

In 2009, for example, the Army had twenty-one MDAPs in various stages of the acquisition process. Out of these programs, only five were being developed as part of an SoS (Spainhower 2009). This includes the FCS, which was in the process of getting cancelled. The integrated architecture needs to take an SoS approach. The Army needs to examine existing systems and their capabilities, develop a comprehensive integrated systems architecture that depicts existing systems, and explore ways that these existing systems could relate to one another from an SoS perspective. Efforts to integrate systems from an SoS perspective have been explored in the DOD SE Guidebook (OSD 2008). The Navy's SoS Engineering Guidebook (OASN [RDA] 2006) also contains an example of an SoS operational architecture that could be adopted by the Army, as seen from the diagram Figure 10.

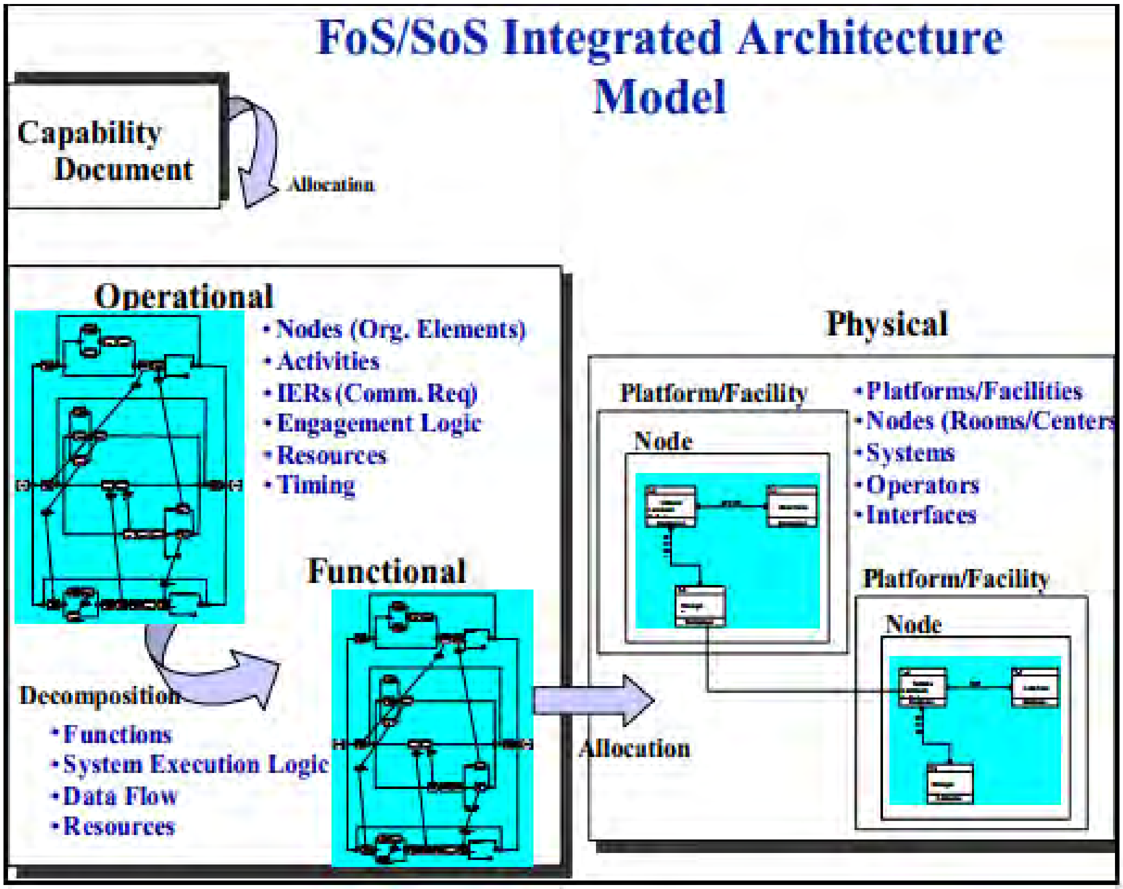

Figure 10. Integrated Architecture Navy SoS (from OASN [RDA] 2006)

Another recommendation to accomplish this integrated architecture at an SoS level is the use of model based systems engineering (MBSE). As discussed in the thesis by Major Tyronne LaStrapes (2012), MBSE has the potential to reduce the inherent complexity of integrating the numerous Army programs into an SoS architecture. Applying and standardizing MBSE automation tools to develop SoS architectures would provide an effective collaboration tool for the numerous stakeholders involved with developing and evolving architectures. The thesis goes on to say that the use of system modeling language can provide a universal language that can be applied to streamline the SoS acquisition process (LaStrapes 2012).

C. CHANGES TO CONCEPT DEVELOPMENT

It is recommended that the Army formally incorporate a DODAF OV-1 for SoS CONOPS development and consider adding other DODAF models as mandatory model requirements for the acquisition process.

One can see from the diagram in Figure 10 that the architecture is decomposed both operationally and physically by constituent systems. This decomposition facilitates a clear understanding of how the SoS functions under different CONOPS scenarios. The Navy also advocates using several other DODAF views, such as the SV-8, System Evolution Description SV-9, System Technology Forecast TV-2, and Technical Standards Forecast (OASN [RDA] 2006, 29). These views can be applied to different phases of the acquisition process to facilitate the SoS engineering process. The Army should incorporate, at a minimum, an OV-1 that models the concepts of operation that will address the capabilities of the SoS as a whole. Other OV-1s may be necessary to diagram complex SoSs under different CONOPS. An integrated SoS architecture analysis should be incorporated as a mandatory part of the acquisition process. Currently, there is no requirement for physically modeling system functions under different CONOPS (Keenan 2013). At a minimum, the OV-1 should be required during the JCIDS process, and published during the ICD. Incorporating the OV-1 will ensure new acquisitions are being examined from an SoS perspective early in the process.

D. CHANGES TO TECHNOLOGY DEVELOPMENT PHASE

It is recommended the Army mandates that private firms demonstrate the ability for technology developments to integrate with an existing or future SoS. Further, the Army should reward private firms that demonstrate innovative ways to use technologies to integrate existing or future systems into an SoS.

A clear SoS architecture will facilitate the technology development required for the SoS. Currently, the technology development in the Defense acquisition system is typically outsourced to private companies to compete for a government contract. This is evident by the news reports of numerous major defense acquisition programs awarded to private firms. Although there is a Research, Development, and Engineering Command

(RDECOM), the Army still contracts a significant portion of their R&D to the private sector. The Army typically funds competing companies to develop a prototype to meet the mission requirements of the Army (Angelis 2013). The private firms then compete and are awarded based on a combination of factors. These factors are heavily weighted on the technological maturity of the prototype, and the cost estimate provided by the private firm (Angelis 2013). This process places an emphasis on the development of a new technology at a low cost. While awarding a contract based on these metrics may seem to be the most efficient process for the Army, an SoS approach could potentially achieve greater cost savings. For example, providing an incentive for private companies to integrate existing Army systems into an SoS would persuade private companies to approach their technological development from an SoS perspective. Currently, companies have no incentive to attempt to integrate existing systems. In fact, private firms that are profit driven generally view it in their best interests to build a new system because of the profit potential. Furthermore, the engineering of individual systems focuses more on the optimization of the individual system. This does not necessarily take into account any present or future requirements that may make it necessary to conduct trade-offs at the system level (Gansler 2009).

As seen in Chapter III with the C-RAM, it is important for systems to accept potentially suboptimal system-level performance in order to optimize the SoS. Incorporating new policies that reward companies for developing technologies with the ability to integrate existing systems to achieve a capability will lead to an emphasis on the SoS engineering process. It will also mitigate some of the risks involved with trying to develop brand new technologies. Developing technologies that facilitate integration with existing Army platforms early in the acquisition process will save time and money. Therefore, before a Milestone B approval occurs, private competing firms should demonstrate in the capability development document (CDD) the ability for technologies to be integrated with existing systems from an SoS perspective. If this is not possible or feasible, this should be explained to the Milestone decision authority before the system is allowed to move to the next phase.

E. CHANGES TO SYSTEM DEVELOPMENT AND DEMONSTRATION

It is recommended that all acquisition funding be initially allocated at the SoS level and divided up into constituent systems based on the each systems' objectives during an SoS acquisition.

The CDD approval at milestone B substantiates the system as a program of record (POR). Under the current acquisition system, each POR has its own line of funding. As pointed out in Chapter III, the C-RAM funding was difficult to track because each individual system had its own line of funding. The acquisition process funding needs to better accommodate the SoS. If the individual systems maintain their own line of funding, then there is little incentive to use system funding to meet SoS objectives. Each SoS should have a POR with funding to cover the integration of each constituent system. There needs to be a detailed process of identifying all constituent systems and making an assessment based on the CDD on how much funding should be allocated at the SoS level. The importance of establishing funding lines and interoperability guidelines early in the acquisition process is underscored in a Carnegie Study referring to an SoS stating that "since the procurement cycles for both systems are driven by their individual requirements and funding lines, the result is that interoperability is delayed for unacceptably long periods of time" (Smith 2009, 8).

The consolidation of SoS funding will pave the way for integration and interoperability early in the acquisition process. An SoS POR should be required before the engineering and manufacturing development phase begins. An SoS POR will also represent a shift in the culture of engineering. Engineers and developers may have to sacrifice the performance of the individual system to achieve a greater performance for the SoS. These trade-offs should be documented and presented to the Milestone Decision Authority (MDA) for milestone C. The decision authority for milestone C should ensure that the SoS is properly scoped before approving production and deployment. A lesson learned from the FCS and the ABCS is that SoSs should understand that the SoS engineering is an iterative process and 100 percent of the capability may not be achieved during the first iteration. The program managers for the ABCS realized this when they determined a set of good enough functions for the initial fielding of the system. This type of decision to reduce the scope was not made for the FCS. The scope actually expanded before production and deployment occurred. Identifying an appropriate scope for each iteration of the SoS development would allow an incremental acquisition that achieves most of the capability objectives, and sets the conditions for future SoS upgrades.

F. CHANGES TO PRODUCTION AND DEPLOYMENT PHASE

It is recommended that SoSs simultaneously test as many constituent systems as feasible during the system development and demonstration phase, and clearly state assumptions used during testing. These assumptions must be clearly articulated in the test plan, and the test plan also must describe the impacts to the system if the assumptions do not hold true.

During the production and deployment phase, low-rate initial production as well as full-rate production occurs for the system. This is also where system test and evaluation (T&E) occurs. SoS testing is challenging when compared with system testing. SoS testing must have all constituent systems present to do a full SoS test. This is often difficult, as pointed out in Chapter II, due to different systems in different phases of the acquisition cycle. SoS testing is also resource intensive, and with funding always being a limited resource in the acquisition process, full SoS testing usually does not occur. Although these SoS challenges will remain in the near future, there are some best practices that should be implemented in the acquisition process.

There must be a balance between testing each constituent system individually and testing the complete SoS. One important practice is to clearly articulate the testing that will have to be simulated due to funding or constituent system constraints. Another important practice is to focus testing on higher risk areas that have the most risk of degrading the SoS capability (NDIA 2012, Slide 7). Applying these testing practices requires a solid understanding of constituent systems and their relationships. This understanding can be achieved by applying the core concepts of SoS engineering to all SoS systems, and maintaining an SoS perspective throughout the acquisition process. Funding for the SoS testing should cover the complete testing of all individual systems as an SoS when possible. When this is not possible, a test plan should identify areas where simulation is substituted for portions of the testing. The test plan should quantify, when possible, the risks involved with the simulation and the assumptions used during the simulation.

One of the problems discussed with the FCS is that many assumptions were used for simulation testing that proved not to be true. The SoS test plan must identify potential consequences for a test assumption not being true, and attempt to validate or invalidate assumptions as soon as possible. The decision authority should take all of this information and determine whether the test needs to wait until more resources become available to do a more thorough SoS test, or plan to address these issues in another iteration of the SoS, or accept the test risks identified and proceed to full production without making arrangements to replace simulated tests with actual tests. This testing should be documented as part of the SoS engineering plan. Currently, according to AR 70–1, there is only a requirement for an SE plan, even for an SoS (Department of the Army 2011). Incorporating a robust T&E plan at the SoS level is essential to the successful fielding of an SoS and should be part of the SoS SE plan.

G. CHANGES TO PROGRAM MANAGER EVALUATION PROCESS

It is recommended that the program manager (PM) evaluation process incentivize the PM’s efforts to integrate his or her program into its SoS framework.

Another process change that is important is the process of evaluating program managers. PMs are currently evaluated primarily based on their ability to develop their program within cost and schedule. The PMs are normally assigned to a program for three years, and during this time frame, most of the focus is on meeting their program objectives in cost and schedule, and little time is focused on interoperability (Blanchette 2005). As a result, there is less of an incentive to incorporate an SoS process that may take funding dollars or time away from the PMs individual programs. The evaluation process should change to incorporate how well the PM understood its individual program within the context of its SoS, and senior raters should evaluate the efforts the program made to integrate and achieve interoperability with other programs. This is not suggesting that cost and schedule requirements should not be evaluated, but that the process change should look at cost and schedule overruns in context, and reward PMs who sacrificed time and money on their individual programs to accommodate the SoS. Organizational changes to facilitate this process will be discussed in Chapter V.

H. CHANGES TO OPERATION AND SUPPORT PHASE

It is recommended that the Army use the SoS wave model as an assessment tool for SoS architectural evolutions, and future SoS updates.

As stated in the second chapter, one of the characteristics of SoS is emergence. During the operation and support phase of the acquisition process, there needs to be a systems assessment period where the system is assessed against required capabilities. Further, additional assessments must be made on emergent capabilities and risks identified during operational use of the SoS. This assessment should be documented and reviewed before any SoS upgrades are executed. Assessing the system at this stage will ensure future SoS upgrades build off of work already completed, and minimize the duplication of effort that would go into developing a capability that was overlooked because of a missed emergent trait.

The wave model should be used in conjunction with the acquisition process to emphasize the process changes discussed in this chapter. It covers the development and evolution of an SoS architecture, the importance of testing, and the importance of SoS evolvement. Figure 11 is an illustration of the wave model.

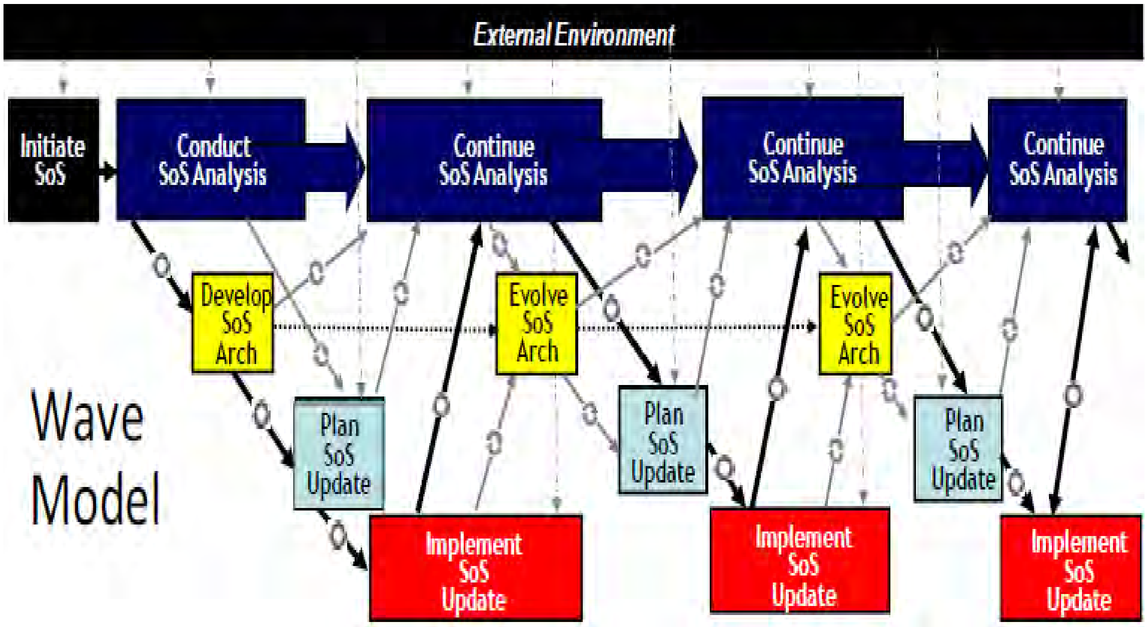

Figure 11. Wave Model (from Dahmann 2012)

This model should be used in conjunction with the current acquisition process to facilitate an SoS approach to acquisitions. The wave model is simple but it emphasizes the iterative nature of the SoS acquisition process. The model focuses on developing and evolving the SoS architecture while planning for the SoS upgrade and implementation in parallel.

Another undertaking that should be incorporated into the acquisition process from an SoS perspective is to establish PORs to take existing systems and integrate them to produce capabilities that may not have come out of the JCIDS process. This also uses the concept of emergence that exists in SoSs. The acquisition process is currently a top-down process, but understanding individual systems and their relationships to one another may lead to a bottom-up process that explores ways that existing platforms or systems can operate together. A bottom-up process may not be driven by a capability gap assessment from the JCIDS; however, the effort could provide meaningful capabilities for the Army in the longer term. The successful integration between systems will lead to increased capabilities for the Army.

This chapter has discussed ways that the existing Army acquisition process can implement an SoS engineering approach to future acquisitions. Chapter V discusses how this SoS approach can be implemented from an organizational standpoint.

V. ORGANIZATIONAL CHANGES TO FACILITATE AN SOS PERSPECTIVE

This chapter focuses on organizational changes that could facilitate the SoS process. Changing the process for SoS engineering requires simultaneous changes in the organization in order to maintain efficiency and effectiveness (Giachetti 2010). The Army currently has an SoS Engineering and Integration directorate. The engineering and integration directorates were combined in 2013. This was a significant step in consolidating the acquisition efforts of Army SoS. However, the Army acquisition process is still very system focused. Further, efforts to integrate the SoS engineering and integration directorate with the current Army acquisition process should take place to facilitate acquisitions from an SoS perspective.

A. CURRENT ARMY ORGANIZATIONAL STRUCTURE

The current organizational chart for Army acquisition, logistics, and technology/Army acquisition executive chart (ASAALT) is listed in Figure 12.

Figure 12. ASAALT Acquisition Chart (from Carroll 2015)

The SoS Engineering and Integration is further divided into current and future programs. They do not, however, have any direct control over the management of acquisition systems or SoS. The Program Executive Officers (PEOs) have the responsibility of managing materiel acquisitions in their respective areas. They can be senior officers or government officials and they serve specifically as planning and budget authorities for all programs in their portfolio (Blanchette 2005). In total, the Army has twelve PEOs. Each may be responsible for one, or several, programs that fall under the PEOs area of responsibility. The PEOs are responsible for integration and interoperability across all their programs, but not necessarily integration between PEOs. PEOs use the framework developed from the JCIDS process to facilitate integration between programs.

B. ROLE OF SOS ENGINEERS IN JCIDS

It is recommended that the Army trains and designates SoS engineers as mandatory stakeholders in the JCIDS process for Army acquisitions.

As pointed out in Chapter IV, JCIDS analysis is supposed to analyze architectures from a joint perspective but the processes and the funding support a service- and PEO-specific acquisition process. This often leads to a system-oriented process that does not benefit from a potential SoS approach. There must be Army SoS representation in the JCIDS process. These members would be responsible for implementing and disseminating the SoS perspective to the PEOs, who would disseminate this information to the program managers. There is currently a gap that exists between the JCIDS process and the way capabilities are delivered to the warfighter. A CSIS study published in 2008 stated, “Although JCIDS ‘socialized’ all participants into thinking jointly about capability needs, the process did not define precisely joint capability gaps or prioritize between them” (Hicks 2008, 59). Although efforts have been made to bridge the gap between the JCIDS and delivering needed capabilities to the warfighter, the process would benefit greatly from Army SoS engineers taking part in the JCIDS process. These SoS engineers must have extensive knowledge of current Army programs so that they can clearly articulate the SoS framework to PEOs. Further, it is essential for these SoS engineers to be involved in the JCIDS process because it is early enough in the acquisition process to get the full benefit of SoS Engineering.

C. ROLE OF THE CHIEF INTEROPERABILITY OFFICER

It is recommended that a Chief Interoperability Officer be assigned to all future Army acquisitions early in the process. This officer will be the authority on all interoperability issues, and ensure that interoperability objectives are met in the JCIDS process.

One of the issues that Army PEOs have identified with the acquisition process is the lack of understanding of interoperability. In an interview conducted with several PEOs, one of the common themes was that program managers did not understand interoperability. PEOs often stated that program managers viewed interoperability as a cost line and did not understand how to implement it within the context of their program (Blanchette 2005). Further, interoperability across programs is a PEO responsibility, but there is no requirement for interoperability between PEOs. As a result, there are PEOs trying to get program managers to become interoperable across programs when they do not clearly understand what needs to be done in order to achieve this interoperability. Blanchette (2005) observes that several PEOs believe that this confusion stems from a lack of central authority on interoperability issues. The report states:

> However, several PEOs identified the need for “one trail boss,” that is, a central authority with the broader perspective on interoperability. One PEO suggested that this authority should reside at the Department of Army or Joint Services level. (11)

This suggests that an authority on interoperability would be beneficial to the acquisition process. They, along with a staff, can set the interoperability guidelines for each SoS program. Additionally, this interoperability authority could mitigate some of the challenges associated with demonstrating a net-readiness capability as required by the JCIDS process. This could prevent incidents like the FCS discussed in Chapter III. In this case, interoperability was a requirement for a new system to be built, but there were no specific guidelines on how the interoperability would occur. The FCS seemed to approach interoperability as an individual system responsibility as each system was built, rather than starting with an interoperability plan and building each system in accordance with the plan. An interoperability authority in the JCIDS process could mitigate some of the problems that occurred during the FCS acquisition process.

D. ROLE OF THE LEAD SYSTEM INTEGRATOR

It is recommended that the Army train personnel in order to make the organizational role of LSI a government function, or at a minimum oversee private companies that assume this role.

Another issue relating to interoperability deals with the LSI concept that was used to develop the FCS. One of the issues with this concept is that integration and interoperability was left up to the contractors, with little government oversight. This was the case with the FCS, where Gansler (2009) states:

> LSIs, however have been given broad, government-like authority to execute acquisition programs that include development of individual system requirements, contracting for their development and procurement, and coordination of development schedule and efforts. (vii)

The research paper goes on to say that the reason the government relies so heavily on the LSI contractor is the lack of organic expertise in the government when it comes to SoS Engineering, interoperability, and integration (Gansler 2009). It is important that the government invests in the personnel that are capable of understanding the role of the LSI. This would, at a minimum, provide oversight to the LSI contractors if the government chooses to contract the LSI job. Ideally, the government would have the organic capability to perform as an LSI for SoS programs. The Army currently has organizations that can foster the knowledge required for an LSI. For example, RDECOM has several organizations that cover a wide spectrum of Army functions and future capabilities. RDECOM can be used to train LSIs for SoS acquisitions. Additionally, expanding the SoS engineering and integration directorate is another option to acquire the necessary expertise to perform LSI functions. Trained LSIs in DOD will limit the authority that the defense contractors have with regard to LSIs. These companies are profit driven as opposed to process driven. Using LSIs from the government will help facilitate the SoS engineering process during SoS acquisitions.

E. ROLE OF THE CAPABILITY PORTFOLIO MANAGER

It is recommended that capability portfolio managers be assigned at the PEO level, and that current and future SoS acquisitions are organized based on the capability manager's area of responsibility as opposed to the PEOs.

Another organizational change that would benefit the acquisition of systems from an SoS perspective is the implementation of capability portfolio managers. The Army currently assigns TRADOC capability managers (TCMs) to programs. These TCMs are assigned as TRADOC counterparts to program managers. They are primarily responsible for incorporating all doctrine, organization, training, leadership, education, personnel, and facilities (DOTMLPF) (Keenen 2013). Assigning TCMs with the PMs ensure that the individual program addresses capabilities across the Army's functional domains; however, these capability managers are not an integral part of the JCIDS process that decides what materiel solutions to develop. As a result, the TCMs are part of materiel development but not involved in the decision process that initiates the materiel development. Capability managers should also be used on a macro level to facilitate the SoS acquisition process. These capability managers should be assigned as counterparts to the PEOs along with the TCMs that are counterparts at the program level. Figure 12 describes the current organization of PEOs, but, as stated earlier, this does not facilitate the interoperability and integration required at the SoS level. Table 4 is from a RAND dissertation that lists eleven of the Force Operating Capabilities (FOC) that the Army uses to categorize systems. Currently, there are no capability managers at this level.

Table 4. Eleven Army FOCs (as cited in Hiromoto 2013, 10)

#	FOC	Example 1	Example 2
1	Battle Command	Command and control	Decision superiority
2	Battlespace Awareness	Intelligence information	Manage knowledge
3	Mounted/Dismounted Maneuver	Mobility	Urban operations
4	Air Maneuver	Aviation support	Reconnaissance
5	Lethality	Precision	Automated fire
6	Maneuver Support	Understand battle space	Freedom of maneuver
7	Force Protection	Personnel protection	Asset protection
8	Responsiveness / Deployability	Airlift / sealift	Theater access
9	Maneuver Sustainment	Power and energy	Force health
10	Training, Leadership, Education	Leadership training	Unit performance
11	Human Engineering	Reduce soldier load	Decrease task complexity

Source: Mackay (2008)

Using capability managers at this level will facilitate clearer boundaries with regards to funding lines. One of the issues with SoS development, as noted earlier, is the often nebulous funding lines. The C-RAM, for example, had difficulty determining how much money was spent on C-RAM efforts as opposed to individual system efforts. Additionally, Capability Set 13 (CS13) is currently under the PEO C3-T, but integration efforts would likely incorporate PEOs from the GCS and the Soldier because the communication systems will be used and tested with equipment outside of the PEO C3Ts area of responsibility. The fact that CS13 potentially incorporates systems from several PEOs underscores the importance of establishing funding at the SoS level. Using capability managers at the PEO level and aligning the funding with the PEO managers could provide a way to fund and budget SoS acquisition programs. Another added benefit of having capability managers at the PEO and program levels is that it could facilitate bottom-up SoS engineering. As alluded to in Chapter IV, SoS and systems engineering is focused on a top-down approach, however, a bottom-up approach of the existing systems to better align them with an SoS would be beneficial when designing a baseline SoS architecture. According to Hiromoto (2013), in 2006 there were 104 individual systems that supported the Lethality and Force Protection FOCs. Table 5 identifies functional categories within the FOCs that had five or more individual systems.

Table 5. Lethality and Force Protection Categories with Five or More Systems (from Hiromoto 2013)

Function	Number of Systems
Air Defense	7
Anti-IED	10
Artillery	5
Ground Vehicles	5
Missiles	12
Small Arms	7
Targeting / Queuing	6
Uniforms & Clothing	6
Vision & Weapon Sights	5

Source: Calculated from R2 Budget Item Justification Sheets

Using capability managers at the program level in conjunction with capability managers at the PEO level will facilitate the bottom-up analysis that is necessary to create an SoS architecture for a number of these individual systems that fall under the same functional category.

Adding personnel to the JCIDS process or the acquisition process may seem like there is another level of added bureaucracy to a system that already takes years to produce complete systems. However, as suggested in the RENO report conducted in 2009, which was referenced in a thesis written by LTC Douglas Cherry (2010), the Army should look at eliminating stovepipe organizations in the G3/5/7. These organizations contribute to a system perspective rather than an SoS perspective, and they are a part of the JCIDS process. The report specifically mentions organizations such as "Aviation (DAMO-AV), Biometric Task Force (BTF), Army Asymmetric Warfare Office (AAWO), Electronic Warfare (EW), and LANDWARNET/Battle Command (LB)" (Cherry 2010, 12). LTC Cherry goes on to suggest replacing these organizations with a capabilities and combined arms directorate. Although this study was conducted in 2009, many of these organizations still exist in the Army in 2015. The Army should take a look at these organizations and eliminate the ones that do not contribute to an SoS approach to acquisitions.

F. CHAPTER SUMMARY

This chapter has discussed potential organizational changes that could facilitate an SoS engineering approach to current and future acquisitions. First, the Army should have an SoS engineer as part of the JCIDS process to ensure that there is an understanding from the beginning of the process on how the new acquisition fits into the greater SoS architecture. Further, the Army needs to have organic personnel that can perform or oversee the role of LSI so the Army does not empower the contractors too much during the SoS process. The FCS is an example of an LSI having too much authority. The Army also needs to expand the role of the capability manager to the PEO level, and align funding based on the eleven major FOCs as opposed to the PEOs. Finally, the Army should look at all stove-piped organizations that currently take part in the JCIDS process and consolidate them into a combined arms or capabilities directorate.

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VI. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this research was to explore the idea of approaching future acquisitions from an SoS perspective. This would require SoS Engineering to take place as well as process and organizational changes to facilitate this culture shift. The study began with a brief history of the evolution of the Army acquisition process that led to an increase focus on SoS programs. The thesis then discussed the major steps of the Army's current acquisition process. The study then focused on addressing the following research questions:

1. What are some of the lessons learned and best practices that can be gleaned from the Army's past attempts at SoS acquisitions?
2. What current processes in the Army acquisition system should change, be created, or be implemented as policy in order to facilitate systems engineering from an SoS perspective?
3. What organizational changes in the Army need to take place to facilitate a successful SoS engineering process?

The literature review discussed pertinent definitions regarding systems engineering and SoS engineering. It went on to discuss the systems engineering process in acquisitions, the SoS engineering model, and the core elements of SoS engineering. The third chapter examined three previous SoS acquisitions by the Army, and analyzed these acquisitions using the core elements of SoS engineering. Using the lessons learned from these three programs, Chapter IV discussed some of the process changes that would facilitate an SoS approach to future acquisitions. The following chapter, building on the lessons learned in Chapter III, and the process changes from Chapter IV, discussed organizational changes, specifically personnel changes that would facilitate an SoS engineering approach to acquisitions.

A. FINAL CONCLUSIONS

The results of this study suggest that an SoS engineering approach to future Army acquisitions is not only possible, but necessary. The Army is part of a joint force with systems that will become increasingly connected. The military is currently divided into Combatant Commands. The Combatant Commanders (COCOM) have the great responsibility of managing any conflict within their region. COCOMs lead a diverse group of forces. A COCOM commander has personnel and equipment from all military branches, but currently the acquisition process is set up so that each branch conducts its own acquisitions, and within the branches, each PEO is responsible for acquisitions in his or her domain. As a result of this process, COCOMs often get redundant systems fielded between services, as well as redundant systems within the services. Currently, the acquisition process does not align with how the military is task organized to fight and win wars. Using an SoS approach with SoS engineering principles would be the first step for the Army to align itself with the way the military is set up to fight wars. The next step would be implementing this SoS approach in a joint environment that incorporates all the military services.

An SoS approach does not mean that individual system engineering principles and practices are obsolete. Developing individual systems will still be important and necessary. The difference with an SoS approach is that the greater system will always be at the forefront when new acquisitions take place. This means that even as the systems engineering for an individual system is being conducted, the individual system should complement the SoS engineering that is being done to the SoS.

The transition from a system-based to an SoS-based acquisition will take a lot of effort. Understanding the relationships between a system and its SoS will require significant coordination and flexibility. Some of the process changes recommended will require a cultural shift from the way the Army has been acquiring systems. For example, the integrated architecture that incorporates DODAF views in the ICD will require SoS engineers who have a complete understanding of constituent systems and their relationships. It will also force designers to think about future systems when designing and building a particular SoS iteration. Engineers that are used to optimizing individual systems will have to operate in trade space and potentially build a system sub-optimally for the greater good of the SoS. Additionally, the way the acquisition force is trained will also have to change. The acquisition force must develop capability managers who can provide macro level management of capabilities in their FOCs. These trained capability managers can assist in providing a better method of funding and cost accounting for SoS acquisitions. Currently, there is not much of an incentive for program managers to sacrifice for the SoS because program managers are focused on delivering their product within cost and schedule. Changing the funding to align with SoS acquisitions will encourage program managers to approach their programs from an SoS perspective.

Perhaps the most important part of this cultural shift is education for the future acquisition workforce. The Army has substantial training on the acquisition process, and systems engineering within the acquisition process, however, SoS engineering is not emphasized in training the future acquisition force. The Army needs to incorporate SoS training in acquisitions. The Army has taken steps to incorporate SoS by establishing an SoS engineering and integration directorate. This directorate has already been beneficial to SoS programs that have leveraged their expertise. The Army should build off of this expertise and look into incorporating some of the process and organizational changes that will facilitate an SoS-approach to future Army acquisitions.

B. RECOMMENDATIONS FOR FUTURE STUDY

There is significant opportunity for further research on this study. This research examined three SoS programs that the Army conducted. There are several other lessons learned from other SoS programs that were not covered. There are also important lessons learned that could be gained from studying individual systems acquisitions. This study examined MDAP acquisition, but there are also several smaller programs that could benefit from a study of how the smaller individual systems would fit into a larger SoS framework. These smaller programs that don’t classify as MDAPs seem to receive less attention because of their lower costs. This research recommends process changes to the major steps of the acquisition process; however, a more in-depth look at some of the underlying processes in the acquisition system should also be examined for potential changes. Additionally, a feasibility study on the proposed changes recommended in this study, as well as any future changes suggested, would be beneficial before these processes were implemented in the acquisition process. Furthermore, this study did not benefit from any specific firsthand accounts of the acquisition process from acquisition professionals, or key members of the acquisition community. Further research should incorporate interviews from PEOs, PMs, and other personnel on their personal experiences with system or SoS acquisitions.

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