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Research on System-of-Systems Acquisition

3 September 2010

by

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Abstract

The acquisition of a system of systems (SoS) is an acquisition of multiple systems that are intended to operate together as a system of systems. Much more common in the U.S. Department of Defense (DoD) is the acquisition of one or more new systems that are intended to interoperate with existing systems as a SoS with new capabilities. In either case, a successful acquisition of a system of systems necessarily depends on effective contracting structures and processes for SoS acquisition. In this paper, we define a set of SoS issues that need to be addressed in SoS acquisition, and we discuss the current findings in this on-going research. Our findings suggest an extensive systems engineering effort be sustained within the SoS acquisition and, to maximize the probability of SoS acquisition success, a change to the existing contracting structures and process and organizational structures

Keywords: system-of-systems (SoS) acquisition; sustainment of extensive systems engineering effort; SoS acquisition issues

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I. Introduction

No universal agreement on a definition of the term *system of systems* exists, but many definitions have basic elements in common. Sage and Cuppan (2001) described a system of systems (SoS) as having operational and managerial independence of the individual systems as well as emergent behavior. Maier and Rechtin (2002) described systems of systems as systems with emergent behavior that are operationally independent, managerially independent, evolutionarily developed, and geographically distributed. Boardman and Sauser (2006) described one of the differentiating characteristics of a SoS as autonomy exercised by the constituent systems in order to fulfill the purpose of the SoS. Other definitions include operational and managerial independence and geographical separations of the constituent systems. Two characteristics of the types of systems of systems normally considered in the U.S. Department of Defense (DoD) acquisition are (1) the constituent systems of an SoS are not chosen, but rather mandated to belong to the SoS and (2) the SoSs are usually bounded. A SoS can consist of to-be-developed systems, existing systems, or some combinations of new and existing systems.

SoS acquisition in the U.S. DoD is faced with many challenges. Some SoS programs have faced technical and management challenges, if not failures. The U.S. Army's Future Combat System program (U.S. Army, 2002) has a serious budget overrun (GAO, 2007, 2008). The U.S. Coast Guard's Integrated Deepwater System suffers from the lack of collaboration between contractors and from the system integrators' inability to impose decisions on the contractors (O'Rourke, 2009).

With an aim to develop approaches that can prevent such SoS acquisition programs from failing, Ghose and DeLaurentis (2008) looked into acquisition management types, policy insights, and approaches to increasing the success of a SoS acquisition. The common causes of failure within SoS acquisition processes are: a) misalignment of objectives among the systems, b) limited span-of-control of the SoS engineer on the component systems of the SoS, c) evolution of the SoS, d) inflexibility of the component system designs, e) emergent behavior revealing hidden dependencies within systems, f) perceived complexity of systems and g) the challenges in system representation (Ghose and DeLaurentis, 2008, 2009). Ghose and DeLaurentis (2008) used the total time to complete the project as a success metric and analyzed the effect of requirement dependency, span-of-control, and risk profiles on it. For example, they found that the acquisition process is completed in 19 time-steps with low span-of-control, as compared to 12 time-steps with high span-of-control. The concept of span-of-control of engineers and managers is also addressed in this paper because it is related to both the pre-acquisition and acquisition phases of SoS acquisition.

Osmundson, Langford, and Huynh (2007) addressed SoS acquisition issues and their resolution by modeling simulation with a focus on SoS systems engineering. These issues included initial agreement to operate as a SoS, SoS control, organization of the SoS, identifying SoS measures of effectiveness and measuring effectiveness, staffing, team building and training for an SoS operation, identifying data requirements, identifying and managing interfaces, managing risk SoS testing, and managing emergent behavior. Each of these issues is briefly discussed here. A detailed elaboration of these issues and their resolution by modeling and simulation can be found in Osmundson et al., (2007).

The work captured in this paper attempts to answer the following question: Can new contracting concepts be developed to aid in maximizing the probability of SoS acquisition success? The usual success criteria for systems acquisition apply: performance, schedule, and budget. The performance criterion requires the SoS perform according to requirements. The schedule criterion requires the SoS be developed within a desired schedule. The budget criterion requires the SoS be developed within a budget. Finally, contracting refers to management policy and guidance, roles, and responsibilities of the federal government and DoD contract management. A detailed elaboration of these contracting elements can be found in Rendon and Snider (2008).

This paper considers a realistic scenario of a SoS acquisition program, represented in Figures 1 and 2. It is realistic in the sense that it reflects some current DoD SoS acquisition programs. Figure 1 shows three separate, autonomous, individual systems: System A, System B, and System C. These systems are currently being acquired (researched, developed, tested, produced, and deployed). Each system is managed by a government program manager and a contractor who is performing in accordance with the requirements of an acquisition contract. During the course of the acquisition of each individual system in this scenario, a new mission arises and requires a SoS to be built that consists of the three systems; the government thus adds a requirement that each individual system become part of the SoS acquisition program. Figure 2 reflects the new SoS acquisition program. The individual systems now must also satisfy the SoS requirements (indicated by the shaded areas). In this paper, the discussion of the contracting structures and processes for SoS acquisition pertains to this scenario.

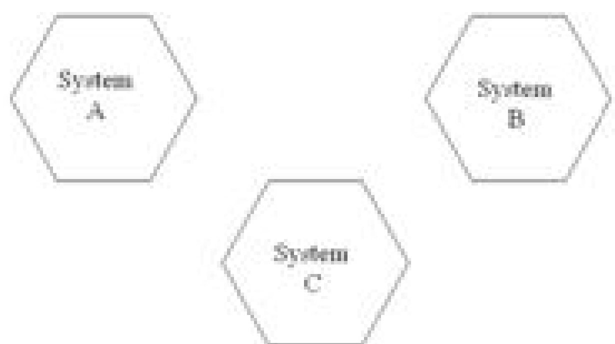

Figure 1. Three Separate Systems Being Developed

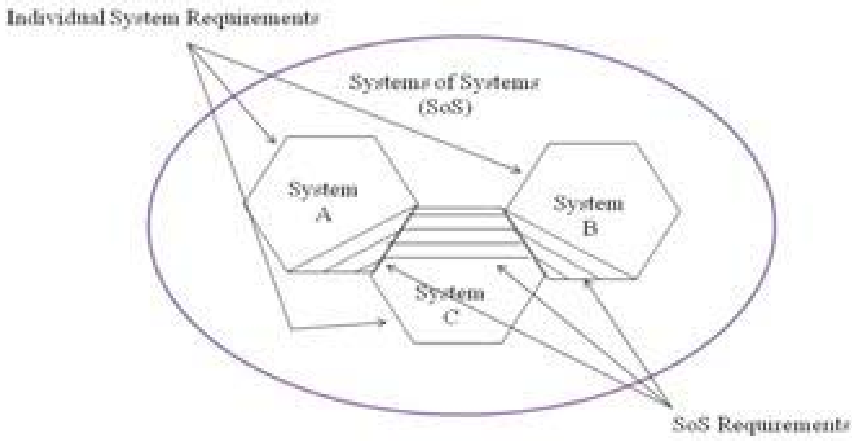

Figure 2. Addition of SoS Requirements

The transition from the acquisition of individual systems to the acquisition of a SoS has implications on the relationship between the government and the contractors. This relationship is also determined by the organizational structure used to manage the SoS acquisition program. Will the required SoS systems engineering be performed by a new, overarching group; by a collaboration among systems-engineering organizations associated with existing systems; or by a single systems-engineering organization associated with one of the component SoS systems? In addition to contracting, organizational structure is also discussed in this paper.

The goals of this paper are as follows.

1. Emphasize the span-of-control of engineers on SoS acquisition during the SoS pre-acquisition and acquisition phases.
2. Examine all possible contracting options in conjunction with all possible organizing options.
3. Arrive at all possible combinations of contracting and organizing options for resolving the SoS acquisition issues.
4. Map the resolution of the SoS issues to the success criteria for SoS acquisition.

We begin the next section of the paper with a quick look at some recent SoS acquisitions. We then discuss the SoS acquisition issues, examine some SoS acquisition–related concepts, and end with a summary of our findings and ideas for future work.

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II. Recent System of Systems Acquisitions

Examples of recent SoS acquisitions are the U.S. Army's Future Combat System, the U.S. Coast Guard's Deepwater System, the Joint Tactical Radio System (JTRS), and Homeland Security's SBInet, each of which has experienced technical, budget, and schedule challenges beyond what is considered usual for single-system acquisitions.

Future Combat System. The Future Combat System (FCS), shown in Figure 3, was originally to be composed of a networked system of new, manned ground vehicles (shown on the right-hand side of Figure 3) and unmanned aerial vehicles (shown on the left-hand side of Figure 3). FCS has recently been scaled back to a networked system of unmanned air and ground vehicles and existing manned ground vehicles.

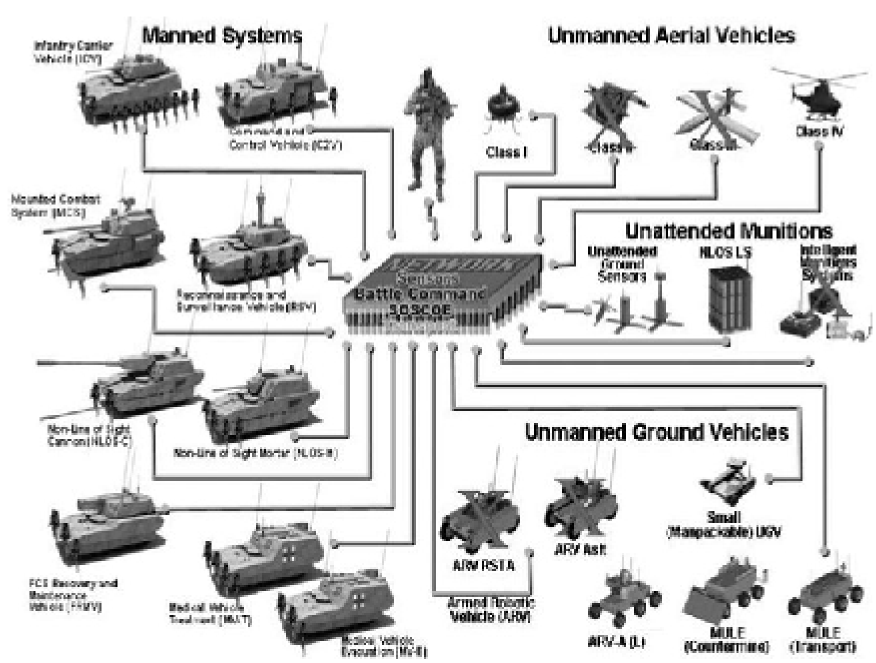

Figure 3. Original U.S. Army Future Combat System Architecture

The initial program cost estimate was $91.4 billion, and the first combat brigade equipped with FCS was expected to roll out around 2015, followed by full production to equip up to 15 brigades by 2030 (Feickert & Lucas, 2009).

Deepwater. Deepwater, shown in Figure 4, originally was to include updated legacy ships plus new national-security cutters, offshore patrol cutters, and fast-response cutters; updated aircraft and new manned and unmanned aircraft; and a new C4ISR system that would provide seamless communications between all of the assets, as shown in Figure 5. The Deepwater program was begun in 2002, estimated to cost between $19-$24 billion, and expected to take 20–25 years to complete. The contract was awarded to Integrated Coast Guard Systems (ICGS)—a joint venture of Northrop Grumman and Lockheed Martin—and ICGS hired subcontractors to design and build new assets. The Deepwater program was not only replacing old ships and aircraft but also was offering an integrated approach to upgrading other existing assets with improved C4ISR equipment and innovative logistics support systems (O’Rourke, 2009). C4ISR is fundamental to improving maritime domain awareness and is designed to ensure seamless interoperability not only among all Coast Guard units but also with Department of Homeland Security (DHS) components and with other federal agencies, especially the Navy.

Figure 4. Original Coast Guard Deepwater Vessels and Aerial Vehicles

Figure 5. Networked Deepwater System of Systems

Joint Tactical Radio System. The Joint Tactical Radio System (JTRS) is a software-defined radio (SDR) that allows a single hardware platform to be reconfigurable so that it can accommodate multiple radio waveforms. JTRS accommodates legacy and new, mobile, ad hoc networking waveforms and can store and run multiple waveforms (Nathans & Stephens, 2007). JTRS is considered a SoS and consists of airborne-maritime fixed site (AMF) radios, ground mobile radios (GMR), handheld, man pad, small form fit radio (HMS), net-centric enterprise services (NCES), GIG bandwidth extension (GIG-BE), and legacy networks. A model of the AMF delivery process is shown in Figure 6. Lockheed Martin was selected to serve as the prime systems contractor (PSC).

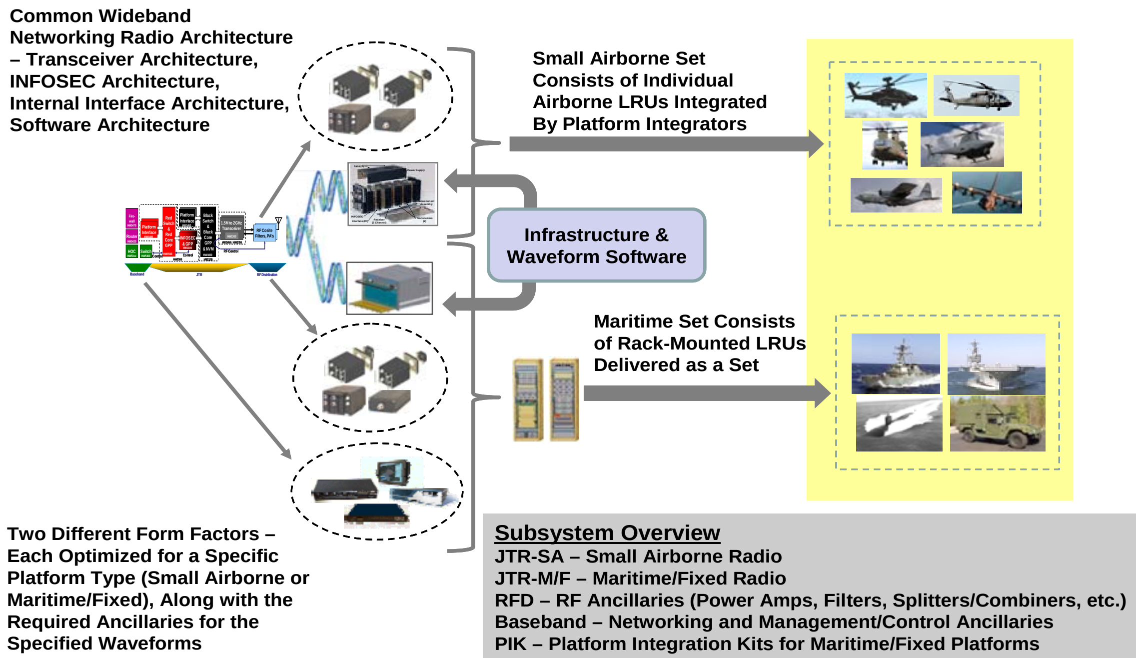

Figure 6. JTRS Airborne-Maritime Fixed (AMF) Delivery Model

(JTRS, 2009)

SBInet. SBInet is a virtual fence designed to detect illegal crossings of the southern border between the U.S. and Mexico. The virtual fence consists of a network of cameras, radars, lighting, and other sensors—some mounted on elevated towers, as shown in Figure 7—and networked through a communication system that includes satellite nodes and links. The original contract was awarded to Boeing Integrated Defense Systems in 2006, and it was intended that the virtual fence would be in place, covering the entire U.S.–Mexico border by 2011. At the time Boeing was awarded the contract, the cost was estimated to be $2.5 billion

(Montalbano, 2010).

Figure 7. SBInet Sensor Tower

Each of these SoS programs has followed a similar acquisition approach: award of a contract to a lead system integrator (LSI) that is supposed to have the responsibility and authority to manage the overall effort. In the LSI model, all four main tasks of building weapons pass from government to industry. The LSI sets functional requirements and system specifications, provides program technical direction, controls program management, and controls program technical execution. The key reasons behind this shift are the growing complexity and scope of such systems while resources within government such as organic acquisition, systems engineering, and program management are getting scarcer.

All of these SoS programs have experienced major challenges: two programs have been restructured with the customer organization taking the LSI role from the private-sector contractor; one program is in hiatus, awaiting further investigation; and the fourth program faces almost certain large cost and schedule overruns.

FCS. There have been significant adjustments to the FCS program since its development started in 2003. The program was restructured and 4 of 18 core systems were cancelled. After the first four years of development, the Army estimated a total acquisition cost growth from $91.4 billion to $160.9 billion although independent estimates were considerably higher—$203.3 billion and $233.9 billion. The program started with immature technologies and only 2 of the program's 44 technologies were fully matured by late 2006, according to the GAO, and it warned that all critical technologies may not be fully mature until the Army's production decision in February 2013. Requirements for networks and software were late, poorly defined, or omitted due to the accelerated schedule for FCS development (Francis, 2009).

Deepwater. As an earlier part of the Deepwater program, the Coast Guard initiated an effort to modernize its existing 110-foot island class patrol boats, so that they could remain in service pending the delivery of replacement Deepwater craft. Among other things, the modernization increased the length of the boats to 123 feet. As a result, the effort is referred to variously as the 110-foot modernization program, the 123-foot modernization program, or the 110/123-foot modernization program. The initial eight boats in the program began to develop significant structural problems soon after the Coast Guard completed its modernizations. The Coast Guard removed the boats from service and canceled the program, having spent close to $100 million on it. The Coast Guard is now pursuing Deepwater acquisition programs as individual programs rather than as elements of a single, integrated program. The Coast Guard is still using a systems approach to optimizing its acquisition programs, including the Deepwater acquisition programs, but that the system being optimized is now the Coast Guard as a whole, as opposed to the Deepwater subset of programs.

The Coast Guard announced in April 2007 that it would assume the lead role as systems integrator for all Coast Guard Deepwater assets. The Coast Guard is phasing out its reliance on ICGS as an LSI for Deepwater acquisition and will terminate the contract with ICGS in January 2011. To support its shift in role to the systems integrator, the Coast Guard is increasing its in-house system-integration capabilities.

JTRS. From its birth in 1997 until restructuring in 2006, the JTRS program experienced cost and schedule overruns and performance shortfalls primarily due to immature technologies, unstable requirements, and aggressive schedules (GAO, 2006b). In December 2009, the JTRS held a stakeholder review after several postponements of a scheduled critical-design review. The stakeholders identified some of the following issues: the baseline in use relied on airborne platform processors to perform many of management functions, and although the platform processor can perform rudimentary radio control functions necessary to meeting the platform mission, relying on the platform processor for performing network management functions was unacceptable; JTRS was having some difficulty meeting NSA information assurance requirements; a large number of requirements allocated by the LSI from upper levels to lower levels were not accepted by subcontractors at the lower levels; there was concern that some waveforms were not ready to be ported to JTRS; the current platform integration kit (PIK) design did not integrate onto some platforms and some platforms did not want to use a PIK at all; and the software design and architecture was not fully defined and the definition needed to include operationally relevant system threads that demonstrated end-to-end capability. The JTRS program's schedule has been extended, and it will also likely cost significantly more than current budget estimates.

SBInet. A GAO report on SBInet released in March 2010 identified a flawed testing process, performance issues, and poor management as serious ongoing issues affecting the program. The Department of Homeland Security cut off funding for the program pending further review. Test plans were poorly defined and plagued by many big, last-minute changes to test procedures, according to the GAO report, and even when the system was tested, it performed poorly. Further, those overseeing the project failed to prioritize solving problems with the system and failed to conduct further tests. The report concluded that if the development and testing of the system were to continue in the same fashion, SBInet would not perform as expected and would take longer and cost more than necessary to implement.

The DHS had expected the entire SBInet project to cost $6.7 billion, a readjustment from its original projected budget of $8 billion. To date, the DHS has spent about $720 million on current SBInet deployments since the project began in 2005. The project was originally scheduled for completion by 2014, but the technical glitches and delays outlined in the GAO report have held up the project so that only a prototype of the final solution is currently in use on just one part of the border. Funding for the SBInet has recently been suspended, pending decisions by the Department of Homeland Security.

III. System-of-Systems Acquisition Issues

Systems acquisition refers to the disciplined management approach for the acquisition of an individual system, such as a weapon system (aircraft, ship, missile, etc.), or of an information technology system. The acquisition process involves the various activities related to the development, design, integration, testing, production, deployment, operations and support, and disposal of the system. Within the federal government, specifically the DoD, systems acquisition uses a program management approach to track these activities. This approach involves the use of a project lifecycle, which includes phases, gates, and decision-points; a project manager; and a project team (Rendon & Snider, 2008). This approach is envisioned to apply to SoS acquisition but also makes use of some new concepts, which are discussed in this paper, because there are significant differences between systems and systems of systems, and these differences affect the nature of government contracting for the development of systems of systems. Such application requires an understanding of the issues associated with SoS acquisition.

What follows is a brief discussion of the aforementioned SoS acquisition issues raised in Osmundson et al. (2007). In this paper, we emphasize the importance of systems engineering ties to the SoS pre-acquisition and acquisition phases and to the contracting process; that is, we emphasize that the span of control of the engineers is crucial in SoS pre-acquisition and acquisition phases.

- Initial agreement refers to decision makers initially getting agreement form all SoS stakeholders that the SoS meets some desirable objective. Initial agreement is an issue in particular when the SoS involves systems from different organizations or Services, because establishing an initial agreement is contingent on quantifying the benefits and risks of the new SoS.
- SoS control must be established: Who will control the SoS, and how it will be controlled? Each partner may lose some measure of control over its own systems in order to enable overall SoS control.

- Organizing is a key issue for the development and operation of a SoS. An example of this is the systems engineering process: How are processes that interface with SoS processes established and monitored?

- Staffing, team building, and training are an issue as SoS operations must be planned for, the skills required for SoS operations must be identified, and personnel with the proper skills must be acquired and trained in SoS operations.

- Data requirement is an issue that deals with the sharing of classified and/or proprietary design information among the SoS partners, who must recognize and weigh the SoS benefits against a possible loss of their systems' operational superiority based on shared, classified, or proprietary design information.

- Interfaces must be identified and managed. Common language, grammar, and usage must be established (for information SoSs), configuration management must be invoked to assure that common agreements are followed, and required information security levels must be identified and provisions to them must be made to assure that security requirements are met.

- Risk management at the SoS level is an issue related to the mitigation of SoS risks potentially affected by component systems, which requires detailed knowledge of component system risks and variations in individual system outputs.

- SoS testing requires that each SoS partner's system be tested in a manner that resolves any concerns about operational behavior. SoS threads must also be tested.

- The measures of effectiveness are an issue because their strong dependence on an individual component system's measures of performance requires an understanding of the latter. This issue is related to the issues of data requirements and interfaces.

- Emergent behavior, exhibited by the SoS and resulting from unknown interactions among the constituent systems or from its interaction with the environment, needs to be collectively understood, analyzed, and resolved, particularly when an emergent behavior may be detrimental to one or more of the partners.

IV. Some SoS Acquisition–Related Concepts

What contracting and organizing options can be used to aid in resolving the SoS issues outlined in this paper? This section discusses these options, their combinations, and the SoS issues.

Cross-Functional Team Model. As previously stated, the government's management of systems acquisition involves the use of project teams. The project team is a cross-functional team that consists of technical specialists from the various functional areas involved in the acquisition process. These functional areas typically include systems engineering, contract management, financial management, logistics, and others. The cross-functional team is led by the government program manager. The program manager has overall responsibility for the success of the acquisition project. Although the program manager has overall responsibility, the program manager may not have all of the authority needed to manage the program. For example, the contracting officer may have the specific authority to award and make changes to the contract. Most systems acquisition programs involve effort from a contractor, but the contract is managed by the government program office. The contracted company will generally have its own program manager and cross-functional team managing the contract for the contractor. Daily communication and coordination between government and contractor program managers, system engineers, and contract managers is the norm in defense acquisition management (Rendon & Snider, 2008). Our focus in this paper is on the systems engineering and contract management of the cross-functional team.

SoS Systems Engineering. Supporting knowledge-based acquisition requires effective SoS systems engineering before the start of the acquisition process. Prior to Milestone A, and prior to the Material Solution Analysis phase that cumulates in Milestone A, an assessment must be made of technology opportunities and resources as well as of user needs (Schwartz, 2010). Assessment of technology opportunities and resources requires a global understanding of the proposed SoS and its operational environment. A technology may be considered mature when it is used in an existing system, but it may lack the required maturity when the existing system is incorporated into the proposed SoS and must operate under new conditions. An example of this is an information systems technology that is mature and stable when operating within the boundaries of a single system, but that lacks the ability to interoperate with other systems.

Technology maturity assessment can also be considered one aspect of risk assessment, which must be treated in the same way that technology maturity is assessed, namely, in the global context of the SoS.

The SoS must be represented clearly, and in sufficient detail, in the pre-Milestone A phase to elucidate SoS technology and risk issues. A clear and complete SoS representation also elucidates data requirements and data ownership issues that will impact contractual relationships. SoS representation is a system architecting task that drives other early SoS systems engineering analyses and requires a high level of skill. Pao Chuen Lui, an INCOSE fellow and retired Singapore Defence Chief Scientist, remarked that although there is a limited number of good systems engineers, there is an even smaller number of systems architects (personal communication, March 2007). Yet, experienced, successful government and industry systems architects are essential at the start of SoS acquisitions. Good systems architecting will not assure program success, but the lack of good systems architecting will almost always result in program failure.

One systems architecting approach is to represent SoSs in an object-oriented manner by using Systems Modeling Language (SysML). Examples of this can be found in Huynh and Osmundson (2007) and in Osmundson et al. (2004). Because SoSs can be represented in an object-oriented modeling language, testing them can be considered similar to integration testing of object-oriented software systems (Binder, 2000). Systems A, B, and C are individually tested first. Then, System B that interacts with System A is integrated with System A, and their combination is tested. Next, System C that interacts with A is integrated with A, and their combination is tested. Then, Systems B and C that interact with each other, are integrated and tested. Finally, Systems A, B, and C are integrated and tested. These integration tests are based on threads of operations analysis, a part of the front-end systems architecting process.

Knowledge of the availability of all systems is required early in the acquisition process in order to develop accurate test plans and program schedules. If a system is unavailable for testing, then a stub or driver is required; stub and driver development require complete knowledge about the missing system.

Thus, prior to Milestone A and during the technology opportunities and resources assessment, there must be a SoS systems engineering team in place that has the high-level skills necessary to develop accurate SoS architectural representations and to conduct technology and risk assessments. High-level systems engineering expertise and systems engineering activities are necessary in order to assure knowledge-based acquisition. Without them, the SoS acquisition would begin with incomplete and possibly inaccurate technology maturity knowledge and risk knowledge.

The concept of span of control on the system components is crucial in all phases of acquisition. This means that the systems engineering discipline needs to be enhanced and ever present in the SoS pre-acquisition and acquisition phases. Toward this end, there are two possible approaches: (1) having a capable SE organization that is strictly organic to the SoS acquisition program office, and (2) using a capable SE organization external to the SoS acquisition program office, which must have strict ownership of the SE organization during the entire SoS acquisition. The advantages of the first approach are that the span-of-control of the engineers takes hold, direct control or exchanges are facilitated, and independence from contractors' undue influence materializes. The disadvantage is the need for investment in money and people. The second approach suffers from control of and an increase in budgets for the same required service and from an increase in time spent on establishing contracts to acquire support from an external organization.

Although the concept of span-of-control is not new, we call in this paper for the span-of-control to exist during the pre-acquisition and acquisition phases.

Contracting Options. The transition from the acquisition of individual systems to the acquisition of a SoS has implications on the relationship between the government and the contractors. This relationship is largely determined by the contracting structure and processes governing the SoS requirements. There are three options for incorporating the SoS requirements into the individual acquisition programs (Programs A, B, and C in the scenario): two separate contracts for each system, replacement of the existing contract for each system, and modification of the existing contract for each system. A discussion of each of these follows.

The first option is to incorporate the SoS requirements (represented by the shaded areas of each system in Figure 2) as a contract distinct from the existing contract for each contractor. Contractors A, B, and C would receive an additional contract with the specific SoS requirements for that system. In this option, each contractor would be working under two different and separate contracts—one for the acquisition of the basic system and one for the SoS requirements related to the basic system.

The second option is to terminate the original contract for the acquisition of the individual system and to negotiate and award a new single contract for both the acquisition of the single system and the acquisition of the SoS components of that system. In this option, each contractor remains with only one contract.

The third option is to negotiate a modification to the existing contract, which incorporates the SoS requirements for that system under the existing contract. In this option, the contractor also remains with a single contract, albeit a modified contract, for all acquisition requirements.

We prefer the third contracting option, modifying the existing contract to incorporate the SoS requirements, over the first option because having a contractor work under two separate contracts may be problematic. For example, there is a risk that the two contracts may be in conflict with each other, such as conflicting specifications, statements of work, or schedule priorities. The resources required for administering two separate contracts would be a disadvantage. Furthermore, managing two separate contracts would complicate organizational structures (discussed in the section on Organizational Structure Options). We prefer the third option over the second option because modifying an existing contract is more advantageous than negotiating a termination agreement on the original contract and more advantageous than negotiating a new contract with the contractor. During these negotiations, it is likely that the contractor would need to stop the acquisition effort, thus impacting the project schedule and cost.

Organizational Structure Options. Different SoS-acquisition contracting options bear some impact on the organizational structures of SoS acquisition programs. As stated previously, the transition from the acquisition of individual systems to the acquisition of a SoS has implications on the relationship between the government and the contractors. This relationship is also determined by the organizational structure used to manage the SoS acquisition program.

In structuring the organization, three organizing options can be used for the SoS acquisition program. The first option is to designate one of the individual programs as the lead program and to make that government program office responsible for managing the entire SoS acquisition program, which includes the other two systems. For example, the government program office managing System A could be designated as the lead program and made responsible for ensuring that Systems A, B, and C meet the SoS requirements. Thus, the government program manager for System A will also have SoS acquisition responsibility and authority over the government program managers for System B and System C.

The second option is to establish a separate government program office that is responsible for the SoS acquisition program. This separate government program office would have SoS acquisition responsibility and authority over the three individual government program offices managing their individual acquisition programs (System A, System B, and System C.) In this option, the SoS acquisition management would be performed by an in-house government acquisition and contracting workforce.

In the third option, a contractor is selected to manage the acquisition of the SoS program. This contractor, typically referred to as a lead systems integrator, would oversee the SoS requirements within the three individual systems (A, B, and C). This option entails awarding a contract to a company to perform the SoS acquisition management.

We prefer the second organizing option, establishing a separate government program office that is responsible for the SoS acquisition program, over the first organizing option, because having one of the individual programs as the lead program and making that government program office responsible for managing the entire SoS acquisition program could result in potential conflicts of interest. The government program manager for the individual program might be biased and might be improperly influenced in the management of the overall SoS acquisition program. In this position, the government program manager might favor the individual program over the needs of the SoS.

We prefer the second organizing option over the third organizing option, because in the latter the contractor could end up determining some of the critical requirements and making acquisition decisions. The third contracting option might result in the outsourcing of inherently government functions related to the acquisition of the SoS program. It might also result in the government's loss of systems-engineering core competency and capacity for managing SoS programs.

Integrating Acquisition Management Processes. In addition to the contracting options discussed in the section on Contracting Options, another SoS issue relates to the integration of the SoS contract requirements among individual contracts. SoS acquisition programs involve a high level of uncertainty and, thus, a high level of risk. Because many of the individual systems have evolving requirements, and because these requirements have to interface with those of the other individual systems in the SoS, the level of integration needed in the acquisition process of each individual system, as well as of the SoS, is very high. Additionally, in SoS acquisition programs, the use of lead systems integrators (LSI) or prime systems contractors who oversee the subcontractors performing the majority of the acquisition effort adds to the high need for integration within the acquisition process. In these SoS acquisition programs, one of the critical challenges is integrating the cost, schedule, and performance elements within the individual contracts (which now include the SoS requirements).

Many agencies respond to the increased uncertainty and risk of SoS acquisition programs by trying to increase the specificity of the contract elements such as performance requirements, contract type, incentive, delivery schedule, and other terms and conditions. Other agencies attempt to increase the flexibility of the contract elements in order to reflect the high uncertainty and risk. This flexibility would be reflected not in the detailed product or performance specifications of the contract, but in the processes established for development of the specifications, testing and acceptance criteria, and cost allowability (Brown, Potoski, & Van Slyke, 2008). We prefer an approach that strikes a proper balance between contract element specificity and flexibility. This can be done through the development of an integrated management system, which is discussed next.

In integrating the major elements of the SoS acquisition cost, schedule, and performance objectives, a best practice is to establish an integrated management system that integrates the planning, monitoring and control, and feedback elements of the SoS acquisition program.

The planning elements include the requirements specification, work breakdown structure (WBS), statement of work (SOW), and the integrated master plan (IMP). The IMP reflects all program activity, expands on the statement of work tasks, and defines the milestones. The IMP also specifies the program events, significant accomplishments, accomplishment criteria, and detailed tasks. The IMP is incorporated in the contract, along with the specifications, WBS, and SOW. However, it should be noted that the IMP is an event-driven plan and does not specify any calendar schedule. The JTRS AMF contract includes an IMP along with a statement of objectives, WBS, performance requirements document, and other specifications.

The monitoring and control elements include the integrated master schedule (IMS), technical performance measures, and the earned value management system. Although not part of the contract, the integrated master schedule provides the detailed calendar schedule for tracking schedule progress, the earned value management systems tracks cost and schedule performance, and the technical performance measurement system tracks the technical risk. The JTRS AMF program includes an IMS as well as technical performance measures and an earned value management system.

The feedback elements include the contract award fee, if any, and contractor-performance assessment reviews. The contract award fee allows the contractor to earn additional profit by performing over and above the required levels of performance. The contractor's performance and any award-fee decisions are based on a subjective evaluation by the government. The contractor performance assessment review is separate from the award fee and applies to all government contracts exceeding the simplified acquisition threshold. The JTRS AMF contract includes an award fee for the design, development, delivery, and testing of the engineering development models.

This integrated management system would be developed and used for each individual system acquisition program, as well as for the SoS acquisition program by the SoS government program office, as discussed in the previous organizational structure options.

Linkages between Contracting Options and Organizational Structure Options. A logical linkage appears to exist between our preferred contracting and organizing options for transitioning from the acquisition of individual systems to the acquisition of a SoS. Our preferred contracting option of modifying the existing contracts to incorporate the SoS requirements and our preferred organizing option of establishing a separate government program office responsible for the SoS acquisition program can be effectively implemented together. The government program office responsible for the acquisition of the SoS would be the requirements agency for the SoS program. In this capacity, the SoS government program office can communicate the SoS requirements to each individual system program office. The system program office would then incorporate these requirements into the individual-system contract modification. The systems-engineering and contract-management personnel from the SoS government program office would communicate and collaborate with the systems engineering and contract management personnel in each of the individual system program offices to manage these SoS requirements.

One potential drawback to the linkage of the two preferred contracting and organizing options would be the potential conflict between the SoS government program manager and the individual-system government program manager (such as between the SoS government program manager and System A government program manager). This would occur in situations dealing with cost, schedule, and performance priorities between the two aspects of the system (individual and SoS). The understanding of and adherence to roles and responsibilities between the SoS government program manager and the individual system program manager, as well as an order-of-precedence clause in the contract, would help deter these potential conflict situations.

Table 1 shows a number of possible combinations of contracting and organizing options (marked with √), which could potentially result in the resolution of the SoS issues and which, in turn, enable satisfaction of the SoS acquisition success criteria (marked with *X*). As discussed in the Contracting Options section, our preferred contracting option for the scenario of interest (see Figures 1 and 2) is the replacement of the existing contract. It can be combined with either the separate government program option, which is, as discussed above, the preferred option, or with the lead systems integrator option. For example, given that the existing contract is replaced by a new one and that either the separate government program option or the lead systems integrator option is adopted, the SoS interfaces issue should be resolved. The resolution of such an issue would enable the satisfaction of the SoS acquisition criteria.

Table 1. Possible Combinations of Contracting and Organizing Options for Resolving SoS Acquisition Issues

	Contracting Option			**Organizing Option**			**Acquisition Success Criteria**		
Issues	Two separate contracts	Replacing contract	Modified contract	Designated individual program	Separate government program	Lead Systems Integrator	Performance	Schedule	Budget
Initial agreement .			√		√	√	X		
SoS control					√	√	X		
Organizing			√		√	√	X	X	X
Staffing, team building, and training			√		√				X
Data requirements			√		√		X	X	
Interfaces			√		√	√	X	X	X
Risk management			√		√	√	X	X	X
SoS testing			√		√	√	X	X	X
Measures of effectiveness			√		√	√	X	X	X
Emergent behavior			√		√	√	X		

V. Conclusion

The purpose of this on-going research is to determine contracting and organizational options that will help to enable successful SoS acquisitions and to apply them to current and future DoD SoS acquisitions.

At this point in our research, we offer the following suggestions:

- In order for a successful SoS acquisition to take place, there must be a sustainable systems engineering effort with an extensive span-of-control by systems engineers within a SoS acquisition.
- Among the possible contracting options, modifying the contract is our preferred option. However, this is not sufficient. An organizing option must also be considered. Coupled with a contracting option, an organizing option would enable resolution of the SoS acquisition issues. As a result, the probability of SoS acquisition success could be improved.

We will apply these findings to a case study, the results of which will be published in a future paper. Furthermore, in a separate paper we will apply a collaboration theory and incorporate it in the organizing options in particular and in the SoS acquisition in general (Huynh, Osmundson, & Rendon, 2010).

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