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Abstract

Acquisition of a system-of-systems can be an all new acquisition of multiple systems that are intended to operate together as a system-of-systems. Much more common in the DoD is acquisition of one or more new systems that are intended to interoperate with existing systems as a system-of-systems with new capabilities. In either case, successful acquisition of systems-of-systems (SoS) necessarily depends on effective contracting structures and processes for systems-of-systems acquisition. In this paper, a set of system-of-systems issues that needs to be addressed in SoS acquisition is identified and the current findings in this on-going research are discussed. The findings suggest sustainment of extensive systems engineering efforts within the SoS acquisition and change to the existing contracting structures and process and organizational structures to maximize the probability of SoS acquisition success. The resulting changes will be applied to current and future DoD SoS acquisitions.

Introduction

No universal agreement on a definition of the term “system-of-systems” exists, but many definitions have common basic elements. Sage and Cuppan (2001) describe a system-of-systems (SoS) as having operational and managerial independence of the individual systems as well as of emergent behavior. Maier and Rechtin (2002) describe systems-of-systems as systems with emergent behavior that are operationally independent, managerially independent, evolutionarily developed, and geographically distributed. Boardman and Sauser (2006) describe one of the differentiating characteristics of an 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 US Department of Defense (DoD) acquisition are that the constituent systems of an SoS are not chosen, but rather mandated to belong to the SoS and that the SoSs are usually bounded. An SoS can consist of to-be-developed systems, existing systems, or some combinations of new and existing systems.

SoS acquisition in the US DoD is faced with many challenges. Some SoS programs have faced technical and management challenges, if not failures. The US Army’s Future Combat System program (US Army, 2002) has a serious budget overrun (GAO, 2002; 2007). The US Coast Guard’s Integrated Deepwater System suffers from the lack of collaboration between contractors and the system integrators’ inability to impose decisions on them (GAO, 2006).

With an aim to develop approaches that can prevent such SoS acquisition programs from failing, Ghose and DeLaurentis (2008) look into “types of acquisition management, policy insights, and approaches that can increase the success of an acquisition in the SoS setting.” They investigate the impact of SoS attributes, such as “requirement interdependency, project risk, and span-of-control of SoS managers and engineers—on the completion time of SoS projects.” Ghose and DeLaurentis (2008; 2009) cite the following:

> the common causes of failure (Rouse 2007) within SoS acquisition processes as: 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.

In their work, they analyze the effect of requirement dependency, span-of-control and risk profiles on, as a success metric, the total time to complete the project. For example, they find that acquisition process completes 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 the work in this paper, as it is related to both the pre-acquisition and acquisition phases of SoS acquisition.

Osmundson et al. (2007) address SoS acquisition issues and their resolution by modeling simulation, but with a focus on SoS systems engineering. These issues include initial agreement to operate as an SoS, SoS control, organization of the SoS, identifying SoS measures of effectiveness (MOEs) and measuring effectiveness, staffing, team building and training for SoS operation, identifying data requirements, identifying and managing interfaces, risk management, 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 are in (Osmundson et al., 2008).

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

This paper treats a realistic scenario of an 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 office and a contractor performing in accordance with the requirements of an acquisition contract. In this scenario, during the course of the acquisition of each individual system, a new mission arises and requires an SoS that consists of the three systems to be built; 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. In this paper, the discussion of the contracting structures and processes for SoS acquisition pertains to this scenario.

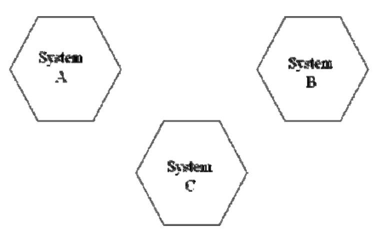

Figure 1. Three Separate Systems Being Developed

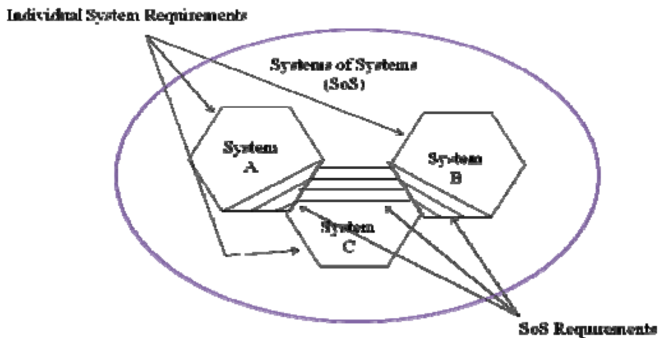

Figure 2. Addition of SoS Requirements

The transition from the acquisition of individual systems to the acquisition of an 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. To emphasize the span-of-control of engineers on SoS acquisition during the SoS pre-acquisition and acquisition phases,

1. To examine all possible contracting options in conjunction with all possible organizing options,

2. To arrive at the possible combinations of contracting and organizing options for resolving the SoS acquisition issues, and

3. To map resolution of SoS issues to the SoS acquisition success criteria.

The rest of the paper begins with a discussion of the SoS acquisition issues, follows with an examination of some SoS-acquisition-related concepts, and ends with a conclusion.

Recent System-of-Systems Acquisitions

Examples of recent SoS acquisitions are the US Army's Future Combat System, the US 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 the usual norm 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 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.

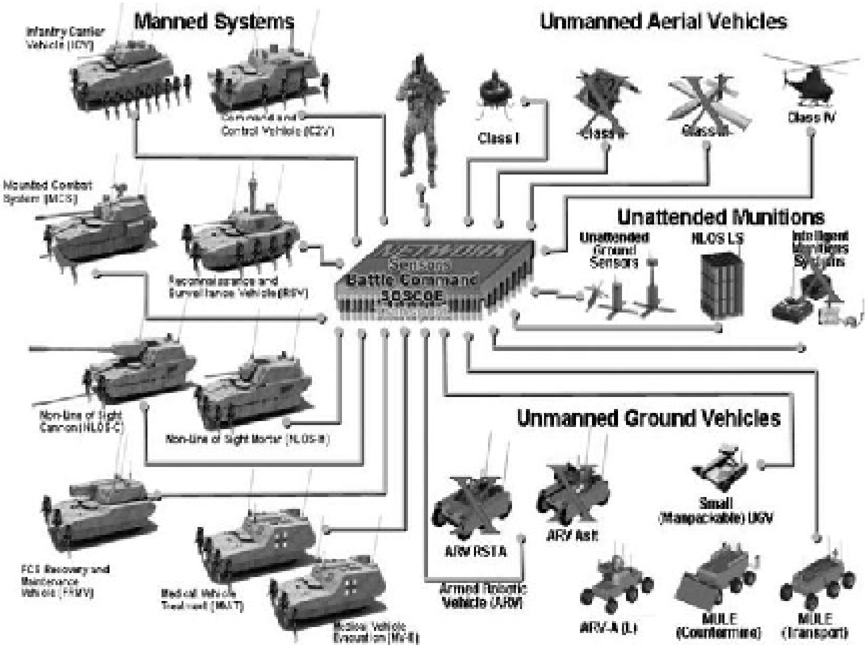

Figure 3. Original US Army Future Combat System Architecture

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 show 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 Northrup 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 was offering an integrated approach to upgrading other existing assets with improved C4ISR equipment and innovative logistics support systems (O'Rourke, 2009).

Figure 4. Original Coast Guard Deepwater Vessels and Aerial Vehicles

Figure 5. Networked Deepwater System-of-systems

The Deepwater program consisted of updating legacy assets and building new classes of cutters, such as the National Security Cutter, the Offshore Patrol Cutter, and the Fast Response Cutter; modernizing aircraft and building a comprehensive, long-term aviation force, including maritime patrol aircraft, unmanned aerial vehicles, and high-altitude endurance unmanned aerial vehicles; developing an integrated logistics support system; and modernizing the Coast Guard's command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) systems to promote seamless communications between assets. C4ISR is fundamental to improving maritime domain awareness and is designed to not only ensure seamless interoperability among all Coast Guard units but also with Department of Homeland Security (DHS) components as well as with other federal agencies, especially the Navy.

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 an SoS and consists of airborne-maritime fixed site (AMF) radios, ground mobile radios (GMR), handheld man pad small form fit radio (HMS), network 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).

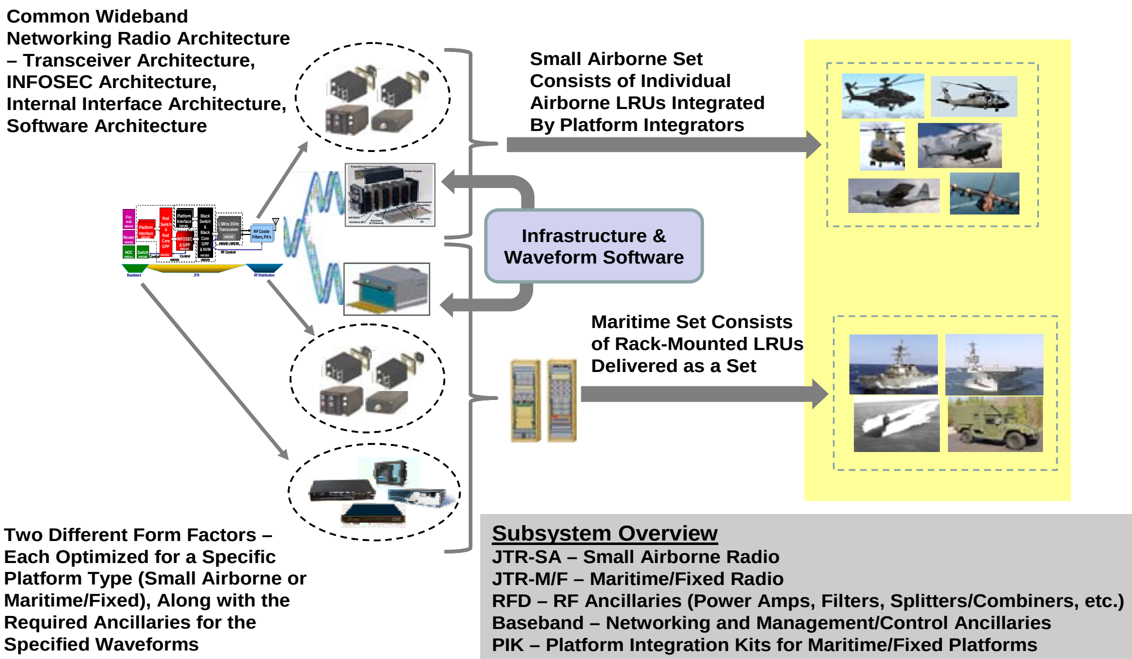

Figure 6. JTRS Airborne-maritime Fixed (AMF) Delivery Model
(JTRS, 2009)

SBInet. SBInet is a virtual fence designed to detect illegal crossings of the US southern border with Mexico. The virtual fence consists of a network of cameras, radars, lighting and other sensors—some mounted on elevated towers, as shown in Figure7—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 US-Mexican 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: contract to a large system integrator (LSI) who is supposed to have the responsibility and authority to manage the overall effort, including those of LSI subcontractors and vendors who number in a range from four to 100 or more. In the Lead System Integrator model, all four main tasks of building weapons have passed 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 organic acquisition, systems engineering, program management resources within government are getting scarcer.

All of the example SoSs have experienced major challenges: two programs have been restructured with the customer organization taking over 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 start 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, while 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, 2008).

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. The effort is thus 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 completing their modernizations. The

Coast Guard removed the boats from service and canceled the program, having spent close to $100 million on it. There were serious problems in the C4ISR system.

The Coast Guard is now pursuing Deepwater acquisition programs as individual programs, rather than as elements of a single, integrated program. The Coast Guard states that it 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 a LSI for Deepwater acquisition and will terminate the contract with ICGS in January 2011. To support its shift to that of the systems integrator, the Coast Guard is increasing its in-house system-integration capabilities.

JTRS. Since its initiation in 1997 until restructuring in 2006, the JTRS program experienced cost and schedule overruns and performance shortfalls, due primarily to immature technologies, unstable requirements, and aggressive schedules (GAO, 2006). More recently, the JTRS held a stakeholders review in December 2009, after several postponements of a scheduled CDR. Some of the recently identified issues are as follows: the current baseline relies on airborne platform processors to perform many of management functions, and while the platform processor will perform rudimentary radio control functions necessary to meeting the platform mission, relying on the platform processor for performing network management functions is unacceptable; JTRS is having some difficulty meeting NSA information assurance requirements; there have been a large number of requirements allocated by the LSI from upper levels to lower levels and not accepted by subcontractors at the lower levels; there is concern that some waveforms are not ready to be ported to JTRS; the current Platform Integration Kit (PIK) design doesn't integrate onto some platforms and some platforms do not want to use a PIK at all; and the software design and architecture is not fully defined and the definition would need to include operationally relevant system threads that demonstrate end-to-end capability. The JTRS program has extended its schedule and 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 "numerous and extensive 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 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 Homeland Security decisions.

Systems-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 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 the management of 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 making use of some new concepts, discussed in this paper, as there are significant differences between systems and systems-of-systems (SoS) and these differences affect the nature of government contracting for the development of systems-of-systems. Such application requires understanding of the issues associated with SoS acquisition.

The aforementioned SoS acquisition issues raised in Osmundson et al. (2008) are now briefly discussed here. In this paper, the importance of SE endeavor ties to the SoS pre-acquisition and acquisition phases and to the contracting process is emphasized; that is, the span of control of the engineers is crucial in these SoS pre-acquisition and acquisition phases.

- Initial agreement refers to decision-makers initially getting agreement that an SoS meets some desirable objective. It 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 of how to organize for the development and operation of an SoS. An example is the systems engineering process: How are processes that interface with SoS processes established and monitored?
- Staffing, team building, and training refer to how an SoS will be staffed and operated. SoS operations must be planned for, the skills required for SoS operations identified, and personnel with the proper skills acquired and trained in SoS operations.
- Data requirements is an issue concerning sharing of classified and/or proprietary design information among the SoS partners, who must recognize and weigh a possible loss of their systems' operational superiority based on the shared classified or proprietary design information against the SoS benefits.
- Interfaces must be identified and managed. Common language, grammar and usage must be established (for information SoSs), configuration management invoked to assure common agreements are followed, and required information security levels identified and provisions made to assure meeting of security requirements.

- Risk management at the SoS level is an issue related to the mitigation of SoS risks potentially effected 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 of its concerns about operational behavior and that SoS threads be tested.
- Measures of effectiveness is an issue because their strong dependence on individual component systems' measures of performance requires an understanding of the latter, and this issue is related to the issues of data requirements and interfaces.
- Emergent behavior, exhibited by the SoS resulting from unknown interactions among the constituent systems or from its interaction with the environment, need to be collectively understood, analyzed, and resolved, in particular when an emergent behavior may be detrimental to one or more of the partners.

Some SoS-acquisition-related Concepts

What contracting and organizing options can be used to aid in resolving the SoS issues? This section discusses these options and the correspondence of their combinations and the SoS issues.

Cross-functional Team Model. As previously stated, government systems acquisition management involves the use of project teams. The project team is a cross-functional team, consisting 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 performed by a contractor with the contract managed by the government program office. The contractor 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). This paper is focused on systems engineering and contract management of the cross-functional team.

SoS Systems Engineering. In order to support knowledge-based acquisition, there is a need for effective global 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. 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 used in an existing system, but may lack required maturity when the existing system is incorporated into the proposed SoS and must operate under new conditions. An example is an information systems technology that is mature and stable when operating within the boundaries of a single system, but lacks the ability to interoperate with other systems.

Technology maturity assessment can also be considered one aspect of risk assessment and in the same way that technology maturity assessment must be made in the global context of the SoS, so must risk assessments.

The SoS must be represented in the pre-milestone A phase clearly, and in enough detail, 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 very high level of skill. P.C. Lui, INCOSE Fellow and retired Singapore Defence Chief Scientist, remarked that while there are a limited number of good systems engineers, there is a very small number of systems architects. 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 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, using Systems Modeling Language (SysML), for example Huynh and Osmundson (2007) and Osmundson et al. (2004). Since SoSs can be represented in an object oriented modeling language, testing SoSs can be considered to be similar to integration testing of object-oriented software systems (Binder, 2000). System A is tested first and then a System B that interacts with System A is integrated with A and the combination is tested; then, a System C that interacts with A is integrated with A and tested; then, if Systems B and C interact together, B and C are integrated and tested, and then A, B and C are integrated and tested. These integration tests are based on thread 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 an SoS systems engineering team in place that has the high-level skills necessary to develop accurate SoS architectural representations, conduct technology assessments 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 systems engineering discipline need be enhanced and ever present in the SoS pre-acquisition and acquisition phases. Toward this end, there are two possible approaches. One is having a capable SE organization strictly organic to the SoS acquisition program office, and the other is using a capable SE organization external to the SoS acquisition program office, but the latter has 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 disadvantages are investment in money and people. The second approach suffers from control and increase in budgets for the same service required of the former, and time spent on establishing contracts to have an external organization to support.

Whereas this concept is not new, this paper calls for it to be instituted and 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 an 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, replacement of the existing contract, and modification of the existing contract. The discussion of each of them follows.

The first option is to incorporate the SoS requirements (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 specific 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.

This paper suggests that the third contracting option, modifying the existing contract to incorporate the SoS requirements, would be preferred over the first option, since 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 below). The third option would be preferred over the second option because modifying an existing contract is more advantageous than negotiating a termination agreement on the original contract and then 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 SoS acquisition program organizational structures. As previously stated, the transition from the acquisition of individual systems to the acquisition of an 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 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 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 the lead program and made responsible for ensuring 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 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 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.

This paper suggests that the second organizing option, establishing a separate government program office responsible for the SoS acquisition program, would be preferred over the first organizing option, since having one of the individual programs as the lead program and making that government program office responsible for managing the entire SoS acquisition program would result in potential conflicts of interest. The government program manager for the individual program may be biased and improperly influenced in the management of the overall SoS acquisition program. In this position, the government program manager may favor the individual program over the needs of the SoS.

The second organizing option would be preferred over the third organizing option because having a contractor manage the SoS acquisition program may involve the contractor performing some of the critical requirements determination and acquisition decision-making of the SoS program. The third contracting option may result in the out-sourcing of inherently government functions related to the acquisition of the SoS program. It may also result in the government's loss of a systems engineering core competency and capability for managing SoS programs.

Integrating Acquisition Management Processes. In addition to the contracting options discussed above, 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. Since many of the individual systems have evolving requirements, and these requirements are required to interface with other individual systems in the SoS, the level of integration needed in the acquisition process of each individual system, as well as the SoS, is very high. Additionally, in SoS acquisition programs, the use of Lead Systems Integrators (LSIs) or prime systems contractors overseeing subcontractors performing the majority of the acquisition effort, also adds to the high need of 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 systems-of-systems 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 to reflect the high uncertainty and risk. This flexibility would be reflected not in the detailed product or performance specifications of the contract, but more in the processes established for development of the specifications, testing and acceptance criteria, and cost allowability (Brown, Potoski & Van Slyke, 2008). A preferred approach is to strike a proper balance between contract element specificity and flexibility. This can be done through the development of an integrated management system, which will be 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 requirement specification, work breakdown structure, statement of work, and the integrated master plan. The integrated master plan (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, based on over and above required levels of performance. The contractor's performance and any award fee decisions are based on a subjective evaluation of 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 developed and used at the SoS level by the government program office responsible for the SoS acquisition program, as discussed in the previous organizational structure options.

Linkages between Contracting Options and Organizational Structure Options. A logical linkage appears to exist between the preferred contracting and organizing options for transitioning from the acquisition of individual systems to the acquisition of an SoS. The preferred contracting option of modifying the existing contracts to incorporate the SoS requirements and the 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 could communicate the SoS requirements to each 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 conflict potential 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, which (marked with "√") potentially result in the resolution of the SoS issues, which, in turn, enable satisfaction of the SoS acquisition success criteria (marked with "X"). As discussed above, the preferred contracting option for the scenario of interest 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 the lead systems integrator option. For example, given that the existing contract is replaced by a new one, either the separate government program option or the lead systems integrator option, the SoS interfaces issue should be resolved. The resolution of such an issue would enable the satisfaction of the SoS acquisition criteria.

Table 1. Resolution of SoS Issues by Option Combinations and Satisfaction of Acquisition Success Criteria

	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		

Conclusion

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

At this point in this research, the following is suggested:

- A sustainable systems engineering effort with an extensive span of control by systems engineers within an SoS acquisition is necessary for a successful SoS acquisition
- Among the possible contracting options, replacing the contract is the preferred option. But that's not sufficient. Organizing options must be considered, for an organizing option must be coupled directly with a contracting option and, together, they would enable resolution of the SoS acquisition issues, which, in turn, could improve the probability of SoS acquisition success, thereby facilitating and effectively managing the SoS acquisition effort.

These findings will be applied to a case study, whose results will be published in a future paper. Furthermore, a separate paper will invoke a collaboration theory and incorporate it in the organizing options in particular and in SoS acquisition in general (Huynh et al., 2010).

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