2012

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Wiley

Rendon, Rene G., Thomas V. Huynh, and John S. Osmundson. "Contracting processes and structures for systemsofsystems acquisition." Systems Engineering 15.4 (2012): 471-482.
http://hdl.handle.net/10945/65884

Regular Paper

Contracting Processes and Structures for Systems-of-Systems Acquisition

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Received 29 August 2011; Revised 31 January 2012; Accepted 1 February 2012, after one or more revisions
Published online in Wiley Online Library (wileyonlinelibrary.com).
DOI 10.1002/sys.21214

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 U.S. Department of Defense (DoD) is acquisition of one or more new systems that are intended to interoperate with existing systems as a system of systems (SoS) with new capabilities. In either case, successful SoS acquisition necessarily depends on effective contracting structures and processes for SoS acquisition. In this paper, a set of issues that need to be addressed in SoS acquisition are identified, and the current findings discussed. The findings suggest maintaining an extensive systems engineering effort within the SoS acquisition and changes to the existing contracting processes, structures, and organizational structures to maximize the probability of SoS acquisition success. The resulting changes are recommended to current and future DoD SoS acquisitions. © 2012 Wiley Periodicals, Inc. Syst Eng 15

Key words: system-of-systems (SoS) acquisition; contracting structures; contracting processes; organizational structures

1. INTRODUCTION

Systems engineering is a critical aspect of defense acquisition management. As the "principal technical discipline that guides the development and production of systems," systems engineering, if performed early in the acquisition lifecycle, can be effective in ensuring the acquisition program meets the cost, schedule, and performance objectives [Rendon and Snider, 2008: 46–47]. The Department of Defense acquisition policy states that "all programs…shall apply a robust SE approach that balances total system performance and total ownership costs within the family-of-systems, systems-of-systems context" [USD(AT&L), 2004: 1]. The acquisition of systems-of-systems increases the complexity of systems engineering, and "the need to coordinate inter-program activities and manage agreements among multiple program managers" [U.S. DoD, 2008: 7].

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 emergent behavior. Maier and Rechtin [2002] describe a system of systems as a system with emergent behavior consisting of systems 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 component systems in order to fulfill the purpose of the SoS. Two characteristics of the SoS types normally considered in the U.S. Department of Defense (DoD) acquisition are that the component 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

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systems, existing systems, or some combinations of new and existing systems [USD(AT&L), 2006].

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] had a serious budget overrun [GAO, 2002, 2007]. The U.S. Coast Guard's Integrated Deepwater System suffered from the lack of collaboration between contractors and the system integrators' inability to impose decisions on them [U.S. GAO, 2006b].

The acquisition challenges faced by the U.S. DoD are similar to the challenges faced by France, United Kingdom, and Germany. These countries "have a similar ambition to acquire products that have not yet been developed and produced to give superiority to the armed forces…to make provision for its definition, development and manufacture to be sure to procure the weapons for the next war and not the last one" [Kausal et al., 1999: 5-3]. Indeed, even within these countries there is concern that acquisition programs may fail to meet cost, schedule, and performance objectives, or that the programs have not been optimally managed [Kausal et al., 1999]. In addition, defense acquisition management in Australia, Japan, South Korea, and Singapore also includes the use of an acquisition life cycle, consisting of phases, review milestones, and decision points, similar to the U.S. In these countries, the military depends on industry "to develop and produce the equipment, the essential training, maintenance, spare parts and other equipment necessary to field an operating weapon system" [Kausal and Markowski, 2000: 6-7]. The SoS acquisition management issues and findings suggested in this paper would also be applicable to these countries' ministries of defense.

With an aim to develop approaches that can prevent SoS acquisition programs from failing, Ghose and DeLaurentis [2008, p. 172] 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, p. 188; 2009, pp. 36–51] cite "the common causes of failure 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 effects of requirements interdependency, span-of-control and risk profiles, as a success metric, on the total time to complete the project. For example, they find that the 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 preacquisition and acquisition phases of SoS acquisition.

Osmundson, Langford, and Huynh [2007] address SoS acquisition issues and their resolution by modeling and simulation, but with a focus on SoS systems engineering. These issues include (1) initial agreement to operate as an SoS, (2) SoS control, (3) organization of the SoS, (4) identifying SoS measures of effectiveness (MOEs) and measuring effectiveness, (5) staffing, team building, and training for SoS operation, (6) identifying data requirements, (7) identifying and managing interfaces, (8) risk management, and (9) 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, Langford, and Huynh [2007].

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 U.S. 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 and 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 being built; the government thus adds a requirement that each individual system become part of the SoS acquisition program. Examples are the U.S. Coast Guard's Deep Water System and the Joint Tactical Radio System (JTRS) discussed in Section 3. Deep Water included legacy systems and systems under development that were to seamlessly interoperate as an SoS. JTRS is a new software radio system under development that is intended to interoperate with a host of legacy systems. Figure 2 reflects the new SoS acquisition program. The shaded areas depict the SoS requirements that are imposed on the systems being developed. In this paper, the discussion of the contracting

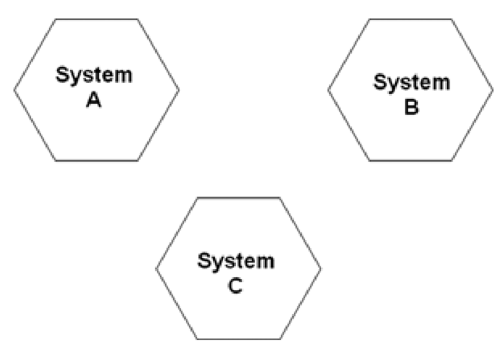

Figure 1. Three separate systems being developed.

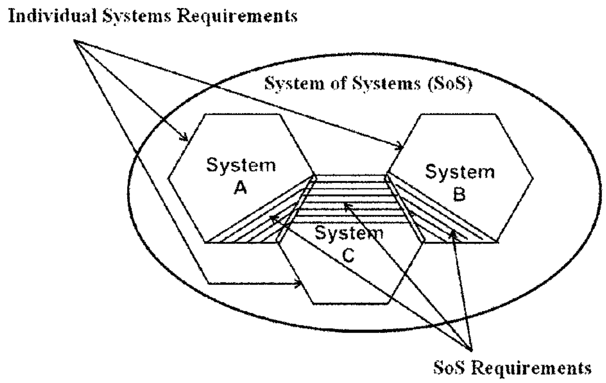

Figure 2. Addition of SoS requirements.

structures and processes for SoS acquisition pertains to this scenario.

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 collaboration among the systems engineering organizations associated with the existing systems, or by a single systems engineering organization associated with one of the component systems? In addition to contracting, organizational structure is also discussed in this paper.

The goals of this paper are:

1. To emphasize the span-of-control of engineers on SoS acquisition during the SoS preacquisition and acquisition phases
2. To examine all possible contracting options in conjunction with all possible organizing options
3. To arrive at the possible combinations of contracting and organizing options for resolving the SoS acquisition issues
4. To map resolution of the SoS acquisition issues to the SoS acquisition success criteria.

The remainder of the paper begins with a literature review on contract structure and organizational design used in acquisition organizations, followed by a discussion of the SoS acquisition issues and an examination of some SoS-acquisition-related concepts, and ends with a conclusion.

2. CONTRACTING PROCESS, STRUCTURE, AND ORGANIZATIONAL DESIGN

Academic research in contract management is founded on several economic and management theories; the most often referred to is agency theory [Williamson, 1987; Eisenhardt, 1989; Mayer and Khademian, 1996; Williamson, 1996; Michaels, 2010; Yukins, 2010]. A contract between the government and a contractor can be analyzed as a principal-agent relationship. The principal (government) contracts with the agent (contractor) to perform a task, such as developing a weapon system. The principal-agent problem occurs because of conflicting goals and objectives between the two parties. In this relationship, the government's objectives include obtaining the product or service at the right quality, right quantity, right source, right time, and right price [Lee and Dobler, 1971]. The U.S. federal government also has the additional objective of ensuring the product or service is procured in accordance with public policy and statutory requirements [FAR, 2011]. Contractors, on the other hand, pursue the objectives of earning profit, insuring company growth, maintaining or increasing market share, and improving cash flow, just to name a few. Because of the different and conflicting objectives between the principal and agent, each party is motivated and incentivized to behave in a manner consistent with its objectives. Agency theory is concerned with the conflicting goals between the principal and the agent in achieving their respective objectives and is focused on mechanisms related to obtaining information (for example, about the marketplace, the supply or service, or the contractor), selecting the agent (to counter the problem of adverse selection), and monitoring the agent's performance (to counter the effects of moral hazard) [Eisenhardt, 1989]. Thus, the contract management process (how contracts are planned, structured, awarded, and administered) has its basis in agency theory [Rendon, 2010].

The contracting process also has a direct impact on SoS acquisition management and resulting outcomes, such as cost, schedule, and performance. The contract management process is usually discussed at the preaward and postaward level of analysis. However, to provide additional granularity and a deeper level of analysis as it applies to SoS acquisition, it is more appropriate to discuss the contracting process using a six-phased lifecycle. These six phases of contract management are Procurement Planning, Solicitation Planning, Solicitation, Source Selection, Contract Administration, and Contract Closeout [Rendon and Snider, 2008]. Each of these contract management lifecycle phases involves specific contracting activities that support SoS acquisition management [U.S. DoD, 2006]. Given the SoS context of this paper, these contract management activities would be performed by any one of the individual system program offices.

Procurement Planning involves the process of identifying which business needs can be best met by procuring products or services outside the organization. This process involves determining whether to procure, how to procure, what to procure, how much to procure, and when to procure [Rendon and Snider, 2008]. This phase of the contracting process includes conducting outsource analysis, determining and defining the requirement, conducting market research, developing preliminary documents such as Work Breakdown Structure (WBS) and Statement of Work (SOW), developing preliminary budgets and cost estimates, and preliminary consideration of contract type and consideration of any special contract terms and conditions. In an SoS acquisition context, the procurement planning activities for each individual system program may need to be performed in coordination with the other component acquisition programs within the SoS program.

Solicitation Planning involves the process of preparing the documents needed to support the solicitation. This process involves documenting program requirements and identifying potential sources [Rendon and Snider, 2008]. This process includes determining procurement method, determining contract type, developing the solicitation document, determining proposal evaluation criteria and contract-award strategy, and structuring contract terms and conditions. The solicitation planning activities of the component system programs in the SoS acquisition program may need to be aligned with each other to ensure success of the acquisition program.

Once the Request for Proposal (RFP) is completed, the Solicitation phase is the process of issuing or deploying the solicitation document and obtaining proposals from the offerors [Rendon and Snider, 2008]. This process includes advertising of the procurement opportunity, or providing notice to interested offerors, and conducting a preproposal conference, if required. Many government agencies have established Web-based systems for centralizing and providing the maximum visibility for the advertisement of procurement opportunities to industry. This ensures a level of integrity, accountability, and transparency in the contracting process.

Source Selection is the process of receiving proposals and applying the proposal evaluation criteria to select a contractor [Rendon and Snider, 2008]. The source selection process includes the evaluation of proposals and contract negotiations between the buyer and the offeror in attempting to come to agreement on all aspects of the contract—including cost, schedule, performance, terms and conditions, and anything else related to the contracted effort. This process includes applying evaluation criteria to management, cost, and technical proposals, negotiating with offerors and executing the contract award strategy. Since the component system program requirement may have a significant impact on the SoS acquisition program, it will be essential for the other component program offices to be involved in the source selection process, especially the evaluation of offeror cost, schedule, and technical proposals, as well as offeror past performance evaluation.

Once the contract is awarded, the contract administration phase begins. Contract administration is the process of ensuring that each party's performance meets the contractual requirements [Rendon and Snider, 2008]. The activities involved in contract administration will depend on the contract statement of work, contract type, and contract performance period. The contract administration process typically includes: monitoring the contractor's work results, measuring contractor's performance, and managing the contract change-control process [Garrett and Rendon, 2010]. In SoS acquisition programs, the contract administration phase is critical for successful acquisition management. It is this phase in which the contractor is performing the contract requirements, and the completed work is then measured and evaluated by the government organization. In the SoS context, given the high risk and complexities of SoS acquisition programs, it will be essential for the other component program offices to be involved in the contract administration process, especially the monitoring, controlling, and measuring of the contractor's performance, as well as the coordination, review, and approval of contract changes.

The final phase of the contracting process is the contract closeout/termination phase. Contract closeout is the process of verifying that all administrative matters are concluded on a contract that is otherwise physically complete [Rendon and Snider, 2008]. The closeout of contracts that are physically complete requires the verification of documentation that reflects the completion of all required contractual actions. A contract is considered to be physically completed when the contractor has completed the required deliveries and the government has inspected and accepted the supplies; the contractor has performed all services, and the government has accepted the services; and all option provisions have expired. The contract closeout process includes final inspection and acceptance of products or services, final contractor payments, and documentation of contractor's final past-performance report. In the SoS context, specific activities such as final inspection and acceptance of deliverables should be coordinated with the other component acquisition programs within the SoS. The contract management process is an important aspect of a system acquisition program. The effectiveness of the contracting process determines the success of an acquisition program [Rendon, 2008, 2010]. Additionally, SoS acquisition programs entail a higher level of complexity and risk, which necessitates the need for effective contract structures and organizational designs, which will be discussed next.

A review of the literature on contract structure reveals many research studies which are beyond the scope of this paper. However, the following research streams seem to emerge from these research studies. These streams include finding the optimum balance between specificity and flexibility and the optimum balance between task-focused and relationship-focused contract structures [Brown, Potoski, and Van Slyke, 2008; Furlotti, 2007; Rahman and Kumaraswamy, 2002].

Brown , Potoski, and Van Slyke [2008] discuss contract structure and design in terms of specificity and flexibility related to six contract design features (inputs, activities, outputs, outcomes; compensation; delivery terms; decision rights; oversight; and proprietary ownership). Specificity relates to the level of detail in the contract in terms of the exchange. Flexibility relates to how adaptable the contract is to changing circumstances, such as new information that occurs during the contract period. Based on their research, contracts for simple products are more specific, whereas contracts for complex products are more flexible.

Furlotti [2007] reviews recent empirical literature on contract design and develops a framework for identifying contracting processes and dimensions, including contract duration, complexity, contingency planning, ambiguity, and specificity. This framework can be further used to guide the design of relational contracts.

Rahman and Kumaraswamy [2002] use transaction cost economics and relational contracting theory to facilitate joint risk management in contracts dealing with uncertainty and complexity. Using Hong Kong-based survey data and a case study in China, they propose a conceptual model for improving project delivery through joint risk management.

Trent [2004] discusses three research streams from the literature on organizational design. These streams include the relationship between strategy and structure, different types of organizational design, and factors influencing organization design. Galunic and Eisenhardt's [1994] research relates organizational structure to organizational strategy and discusses how organizational structures and related processes must adapt to changes in organizations' competitive strategy and environment. This is also supported by Chandler's [1962] research on contingency theory and his statement that structure follows strategy.

Dobler and Burt [1996] discuss the two major types of organizational design (centralization and decentralization) and their advantages and disadvantages. Advantages of centralization include greater buyer specialization, consolidation of requirements, easier coordination and control, and effective planning and research. Advantages of decentralization include easier coordination with operating departments, speed of operations, effective use of local sources, and plant autonomy. A third type of organizational design is the hybrid model, in which procurement functions are shared between a centralized procurement department and decentralized business units [Trautmann, Bals, and Hartmann, 2009].

Johnson, Leenders, and Fearon's [1998] research on the influence of organizational factors on purchasing activities indicates that organizational structure is a good predictor of purchasing involvement in major corporate activities. Furthermore, organizations with centralized purchasing structures report consistently higher involvement in major corporate activities and greater use of selected purchasing techniques as compared to those organizations with decentralized structures.

The reviewed procurement literature reflects the investigation of contract structure in the areas of finding the optimum balance between specificity and flexibility, and between task focus and relationship focus. The review of the literature also includes the investigation of procurement organizational structure in the areas of strategy and structure, different types of organizational design, and factors influencing organization design. However, the review did not identify any research related to contract structure and organizational design in the context of SoS acquisition. The research captured in this paper fills this gap. It is discussed in the next section.

3. 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 design, development, integration, testing, production, deployment, operations and support, and disposal of the system. Within the U.S. 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 and Snider, 2008].

This approach is envisioned to apply to SoS acquisition, but making use of some new concepts, discussed in this paper, as there is a significant difference between acquisition of individual systems and of systems of systems and this difference affects 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, Langford, and Huynh [2007] are now briefly discussed. This paper emphasizes the importance of systems engineering (SE) endeavor (the span of control of the engineers) tied to the SoS preacquisition and acquisition phases and to the contracting process is emphasized.

- *Initial agreement* refers to decision makers initially getting agreement that an SoS meets some desirable objectives. It is an issue in particular when the SoS involves systems from different organizations or military 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 development 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 system's 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 affected by component systems, which requires detailed knowledge of component system risks and variations in individual system outputs.
- *SoS testing* requires each SoS partner's system be tested in a manner that resolves any of its concerns about operational behavior and SoS threads be tested.
- *Measures of effectiveness* is an issue because their strong dependence on individual component system's 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 component systems or from its interaction with the environment, needs to be collectively understood, analyzed, and resolved, in par-

ticular when an emergent behavior may be detrimental to one or more of the partners.

Four recent acquisitions, the U.S. Army's Future Combat System, the U.S. Coast Guard's Deep Water System, the Joint Tactical Radio System (JTRS), and Homeland Security's SBInet, have been examined as case studies of SoS acquisitions.

Future Combat System. The Future Combat System (FCS) was originally to be composed of a networked system of new manned ground vehicles and unmanned aerial vehicles The initial program cost estimate was $91.4B 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 and Lucas, 2009].

There have been significant adjustments to the FCS program since its development started in 2003, and FCS has been scaled back to a networked system of unmanned air and ground vehicles and existing manned ground vehicles. The program was restructured and four of 18 core systems were cancelled. After the first 4 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 two of the program's 44 technologies were fully matured by late 2006, according to the U.S. GAO [2007], and the GAO 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].

Deep Water. The Coast Guard's 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 was considered fundamental to improving maritime domain awareness and was intended to be 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.

The Deepwater program was begun in 2002, estimated to cost $19–24 billion, and expected to take 20–25 years to complete. The contract was awarded to Integrated Coast Guard Systems (ICGS), which served as a lead systems integrator (LSI). ICGS was a joint venture of Northrop Grumman and Lockheed Martin, and ICGS hired subcontractors to design and build new assets [U.S. GAO, 2006a].

As the program progressed, serious deficiencies were discovered in the modernization of its existing 110-ft Island class patrol boats, and there were also serious problems in the C4ISR system. The Coast Guard announced in April 2007 that it would assume the lead role as systems integrator for all Coast Guard Deepwater assets [Brown, Potoski, and Van Slyke, 2008]. The Coast Guard phased out its reliance on ICGS as a LSI for Deepwater acquisition and terminated the contract with ICGS in January 2011. To support its shift to that of the systems integrator, the Coast Guard increased its in house system-integration capabilities.

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 and 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. Lockheed-Martin was selected to serve as the Prime Systems Contractor (PSC).

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 [U.S. GAO, 2006b]. In December 2009, the JTRS held a stakeholders review, after several postponements of a scheduled critical design review. Some of the identified issues were: 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 does not 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. SBInet is a virtual fence designed to detect illegal crossings of the U.S. southern border with Mexico. The virtual fence consists of a network of cameras, radars, lighting, and other sensors—some mounted on elevated towers—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.–Mexican border by 2011. At the time Boeing was awarded the contract, the cost was estimated to be $2.5 billion [Montablbano, 2010].

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, p. 2, and even when the system was tested, it performed poorly. Furthermore, 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 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.

Each of these four case studies experienced one or more failures in ensuring the principle of knowledge-based acquisition was followed. Supporting knowledge-based acquisition requires 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 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 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 information systems technology that is mature and stable when operating within the boundaries of a single system may lack 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 in which technology maturity is assessed, namely, in the global context of the SoS.

Testing SoSs can be considered to be 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 which 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.

4. 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 between their combinations and the SoS issues.

4.1. 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 generally has 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 and Snider, 2008]. This paper is focused on systems engineering and contract management of the cross-functional team.

4.2. SoS Systems Engineering

The concept of span of control on the system components is crucial in all phases of acquisition. This means that SE discipline needs to be enhanced and ever present in the SoS preacquisition and acquisition phases. Many authors have addressed the challenges of effectively applying systems engineering to SoSs. Oxenham [2010] and Mackley, Dean, and John [2010] identify challenges and potential solutions facing systems engineers in defense acquisition and address systems engineering approaches in areas that require more agile responses. As Nidfiffer [2006] said, "A key challenge is how to obtain a better alignment of good acquisition and system engineering principles." Kaplan [2005] pointed out that setting and coordinating mission and system requirements and resources across spheres of influence is a challenge in SoSs. Chen and Clothier [2003] concluded that handling SoS challenges requires managing systems engineering activities across projects and system domains. Toward this end of enhancing the SE discipline in the SoS preacquisition and acquisition phases, 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 increases 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 preacquisition and acquisition phases. This call is not without support, as demonstrated in Heng [2011], front-end SE activities in an SoS SE process enhances the success of SoS acquisition, reflected by reduced mean activity processing time for key activities such as implementing changes/modifications to systems, the system's verification in satisfying SoS requirements, integrating and synthesizing the SoS, and testing and validation of the SoS.

4.3. 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 Fig. 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 individual system and one for the SoS requirements related to the individual 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. The preferred contracting option, modifying the existing contract to incorporate the SoS requirements, is not without issues. First, time and resources are still needed to add modifications to the existing contract. Second, the preferred option is predicated on the assumption that the set of added SoS requirements is relatively smaller than that of the original system requirements. If the added SoS requirements constituted a major portion of the total requirements or exceeded the existing requirements, then replacing the existing contract would be a preferred option. Finally, care must be taken to ensure that the modified contract will not be used as a device to correct the contractual weaknesses discovered after the existing contract is in place.

4.4. 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 component systems to the acquisition of an SoS has implications on the relationship between the government and the contractors, and even among the government program offices. 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 component programs as the lead program and make that government program office responsible for managing the SoS requirements of each component system acquisition program (A, B, and C). For example, the government program office managing System A could be designated the lead program and made responsible for ensuring that component systems (A, B, and C) meet the SoS requirements. Thus, the government program manager for System A will also have acquisition authority and responsibility over the component system program managers for the SoS requirements for System B and System C. The component system program managers will still maintain authority and responsibility for the acquisition of the non-SoS portion of their respective component system.

The second option is to establish a separate government program office responsible for the SoS requirements of each component system acquisition program (A, B, and C). This separate SoS program office would have specific acquisition responsibility and authority for the SoS requirements imbedded in the three individual component systems. The component system program managers will still maintain authority and responsibility for the acquisition of the non-SoS portion of their respective component system. Thus, in this option, the SoS program manager works with each of the component system program managers in managing the component systems' acquisition process.

In the third option, a contractor is selected to manage the SoS acquisition program. This contractor, typically referred to as a Lead Systems Integrator, would be responsible for the SoS requirements of each component system acquisition program (A, B, and C). This option entails awarding a contract to a company to perform the SoS acquisition management for each component system.

This paper suggests the adoption of the second organizing option, establishing a separate government program office responsible for the SoS requirements of each component system acquisition program (A, B, and C). The second organizing option would be preferred over the first organizing option. Having one of the component programs as the lead program and making that government program office responsible for managing the SoS requirements of all component systems would result in potential conflicts of interest between the lead component program manager and the other two component program managers. The lead component program manager may be biased and improperly influenced in the management of the overall SoS acquisition program. In this position, the lead component program manager may favor the requirements of the component program over the requirements of the SoS program.

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

As discussed in Section 2, agency theory and specifically the principal-agent relationship are often used to analyze the buyer (government) and seller (contractor) relationship in defense acquisition programs. However, in the SoS acquisition program scenario and organizing options discussed in this paper, agency theory also applies to the relationship between the SoS program office and each of the component system program offices. The SoS program office and each of the component system program offices will have conflicting goals and objectives directing their acquisition management execution. The SoS program office will be focused on the SoS requirements and meeting the cost, schedule, and performance of those requirements, while the component system program offices will be focused solely on their component system requirements. Additionally, the source and scope of authority provided to the SoS program office to direct and oversee the component system program office acquisition effort will also have an impact on the relationships between the SoS and component system program offices.

Therefore, the implementation of the second organizing option requires clearly defined charters and policies governing reporting and responsibility relationships among the SoS and component program managers. Not only must the issue regarding component system program managers reporting to more than one master be resolved, but the issue regarding the relationships among component system program managers must also be addressed. Confusion and chaos resulting from undefined or misunderstood relationships would impede the management of the integration of the SoS requirements, hence the success of the SoS acquisition as well as that of the acquisition of the component systems.

4.5. 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 component 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 requirements of each component system acquisition program (A, B, and C) can be effectively implemented together. The SoS program office responsible for the acquisition of the SoS requirements would be the requirements agency for the SoS program. In this capacity, the SoS government program office can communicate the SoS requirements to each component system program office. The component system program office would then incorporate these SoS requirements into the component 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 component system program offices to manage these SoS requirements.

One potential drawback to the linkage of the preferred contracting and organizing options would be the agency theory-related conflict between the SoS government program manager and the component 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 (SoS and component). The understanding of, and adherence to, roles and responsibilities between the SoS government program manager and the component system program manager, as well as specific contract terms and conditions, such as an order of precedence clause in the contract, would help deter these potential conflict situations. Given the current defense acquisition culture of policy without practice (in which acquisition policy is not necessarily practiced nor enforced), it is recommended that strengthened acquisition management governance practices, such as program management reviews, milestone decision meetings, and contract change boards, be implemented, thus providing additional visibility and ensuring compliance with both SoS and component acquisition requirements.

Table I 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, enables satisfaction of the SoS acquisition success criteria (marked with "X"). As discussed above, the preferred contracting option for the scenario of interest is the modification of the existing contract. This contracting option can be combined with either the separate government program office option, which is, as discussed above, the preferred option, or with the lead systems integrator option. For example, given that the existing contract is modified to include the SoS requirements, either the separate government SoS program office option or the lead systems integrator option, the SoS interfaces issue should be resolved. The resolution of such an

Table I. Resolution of SoS Issues by Option Combinations and Satisfaction of Acquisition Succ ess 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		

issue would enable the satisfaction of the SoS acquisition criteria.

5. CONCLUSION

The purpose of this paper is to determine contracting and organizational options to enable successful SoS acquisition and to apply them to current and future DoD SoS acquisitions. The following is suggested:

> Sustainable systems engineering effort with an extensive span of control by systems engineers within an SoS acquisition is necessary for a successful SoS acquisition. Having a capable SE organization strictly organic to the SoS acquisition program office is recommended as opposed to using a capable SE organization external to the SoS acquisition program office. This implies an investment in money and people in order to build up SE capability within the acquisition program office. One solution is to create a core team of systems engineers—well versed in SoS systems engineering—within the DoD. SoS acquisition program offices would then draw on core team members to staff a program organic SE organization. This concept is consistent with the systems engineering approach recommended in the Department of Defense Systems Engineering Guide for Systems of Systems [U.S. DoD, 2008] and the concept could be tested using a pilot program, or possibly using modeling and simulation, such as described by Hubbard et al. [2010]. The higher levels of complexity and risk inherent in SoS acquisition programs necessitates an increased importance be placed on the acquisition contracting processes. Procurement planning, solicitation planning, source selection, and contract administration activities of any of the component systems should be performed in a coordinated and collaborative manner with the other component acquisition program offices. Just as the contracting process is a critical factor in the success of any individual acquisition program, the alignment of the contracting processes with each of the other component acquisition programs will be a factor in the success of the overall SoS acquisition program. In addition, among the possible contracting options, modifying the contract is the preferred option. But that is 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, and thereby facilitating and effectively managing the SoS acquisition effort.

A next step in enabling successful SoS acquisition is suggested to be the development and implementation of a Web-based collaboration system (WBCS) in a pilot SoS acquisition program within DoD. As discussed in Huynh, Osmundson, and Rendon [2011], this WBCS will be an instrument to enable successful collaboration and alignment of the individual system programs within an SoS acquisition program.

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