Towards a Work Breakdown Structure for Net Centric System of Systems Engineering and Management

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Abstract. As the system engineering industry sees an increasing focus on the lifecycle development, acquisition, and sustainment of net-centric Systems of Systems (SoS), organizations find that current processes and tools need to evolve to handle the increased scope, scale, and complexity of these efforts. One such tool, the Work Breakdown Structure (WBS) is important in planning, monitoring, and re-focusing of program activities as requirements and goals of the program evolve. This paper provides an overview of the limitations of current standard WBSs with respect to SoS efforts and presents a proposed WBS structure that more adequately reflects the evolving processes and cross-organizational complexities.

INTRODUCTION

We are surrounded by a growing trend in industry and the Department of Defense (DoD) to "quickly" incorporate new technologies and expand the capabilities of legacy systems by integrating them with other legacy systems, Commercial-Off-the-Shelf (COTS) products, and new systems. With this development approach, we see new activities being performed to define the new architecture, identify sources to either supply or develop the required components, and then to integrate and test these high level components, often as a series of incremental or evolutionary steps. Along with this "system-of-systems" development approach, we have seen a new role in the development process evolve to perform these activities: that of the Lead System Integrator (LSI). It is the LSI that has overall responsibility for the lifecycle development, acquisition, and sustainment of the SoS. LSIs are finding that traditional system engineering processes often do not adequately address the increased scope, scale, and complexity of SoS programs and they are continually evolving their processes and tools to meet new needs. A key part of this effort is planning and coordinating the multitude of suppliers that are responsible for the development and modification of system components to be integrated into the SoS, tracking progress, and re-planning to accommodate evolving stakeholder requirements and needs, technology changes, and progress to date. The primary tool used to capture and maintain this information is the Work Breakdown Structure (WBS).

The following sections discuss the limitations of current standard WBSs with respect to SoS efforts, identify some emerging features of SoS developments that need to be reflected in WBSs,

introduce some basic SoS foundations and assumptions, describe a candidate tailorable WBS structure that more adequately reflects the evolving processes and cross-organizational complexities found in SoS programs, and then concludes with some anticipated benefits from the use of this proposed WBS.

MOTIVATION AND GOALS

Standard WBSs, along with systems engineering processes and activities, have been long defined and used at the system level for typical systems of interest (Bracamonte 1993, DoD 1993, DoD 2000, Electronic Industries Alliance 1999, ISO 2002, and Ruskin 2004). However, none exists at the SoS level, since the system-level WBSs do not adequately scale to this higher level. There is evidence that SoSs possess significantly unique characteristics that are not part of the consideration at the single system level (Boehm et al. 2005, Dickerson 2004, Jain et al. 2005, Jamshidi 2005, Lane et al. 2005, and Sage 2001). The following sections describe some of the unique SoS lifecycle characteristics and program needs for tracking SoS development and sustainment activities throughout the full SoS lifecycle.

Context and Background. In various discussions related to SoSs, there is much debate over *what is* and *what is not* a relevant "system of systems", partly because the concept of an SoS is not well understood and has diverse definitions for each application domain (Jamshidi 2005 and Lane et al. 2005). Arguments persist on whether simple scalability of traditional systems engineering activities would suffice for SoS development programs, or if we are facing a significantly different situation. There have been increasing needs and interests in understanding the scope of system of systems engineering, the processes and activities applied, and the estimated cost for acquiring and sustaining such an environment. It is apparent that a systematic approach must be taken to look at the problem comprehensively and the WBS is an effective way to further understand these issues. The WBS captures an important view of the SoS concept and reflects the initial thought process that the authors have had in their pursuit and understanding of this general topic.

Constructive SoS Integration Cost Model (COSOSIMO) surveys (Lane 2005) indicate that while the SoS activities are similar to more traditional system engineering activities, the length, breadth, depth, and associated complexities are much greater. Further analysis of the LSI effort (Boehm et al 2005) identifies additional activities that while not new, have not warranted much attention within the WBS. For example, the LSI begins initial planning and architecting activities. As soon as basic concepts are sufficiently developed, source selection of supplier vendors begins. As suppliers start coming on board, it is important to begin teambuilding activities (many of the SoS vendors have been competitors in the past and now need to work together). In addition, feasibility analyses must be conducted with respect to the selected suppliers and adjustments made to the architecture if necessary. Because of the complexity and high requirements volatility often associated with these types of programs, these systems are often developed using an incremental or spiral development process. Significant effort is expended planning and adjusting the incremental SoS builds in response to changing requirements, current operational needs, evolving technology, and rate of progress of the suppliers.

In order to accommodate continual change, yet stabilize certain aspects long enough to achieve incremental progress in the overall SoS development, many LSI organizations are integrating planned-driven processes with more agile processes (Boehm et al. 2005). Boehm 2005 uses Observe, Orient, Decide, Act (OODA) loops, shown in Figure 1, to describe the process used by many to plan and adjust to the dynamic SoS environment.
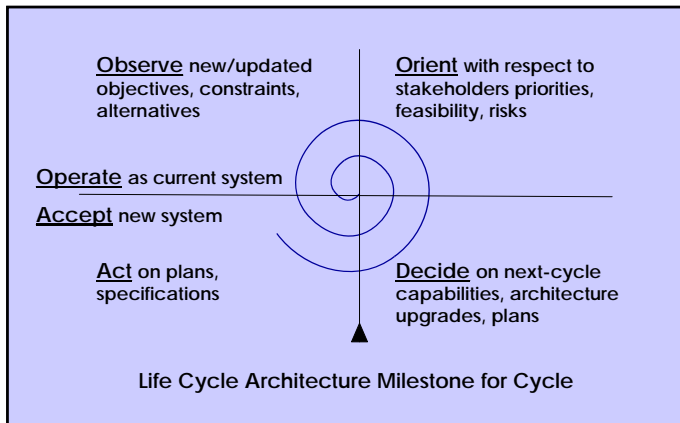
Figure 1. SoS OODA Process (Boehm 2005).

Agile, forward-looking teams are responsible monitoring current system/SoS usage as well as performing Intelligence, Surveillance, and Reconnaissance (ISR) activities to determine the future trends or impacts due to competition, technology evolution, and marketplace demands. Part of this includes monitoring the continual, independent upgrade of the SoS system components. Many of the SoS component systems are existing operational systems with their own on-going enhancement and sustainment activities. Long term success of the SoS depends on the effective coordination of SoS capabilities with the evolution of the system component capabilities.

Next, the agile teams need to orient future increment plans with respect to stakeholder priorities; cost, schedule, and technology feasibility; and risks. This is often achieved through risk and opportunity analysis, business case and mission analysis, and prototypes, models and simulations. After orientation activities are complete, a decision is made on the capabilities to include in the next increment or build of the SoS. This typically results in adjustments to the SoS architecture and plans.

At this point, the development of the increment transitions to a more plan-driven team. The plans and requirements for the build are stabilized so that the plan-driven team can proceed relatively uninterrupted with the development of the current build. Changes are seldom made to plan-driven efforts, but rather given to the agile team for impact analysis and incorporation into a future increment.

The other key aspect of this process is continual verification and validation (V&V). This is part of the on-going feasibility assessments as well as the assessment of the plan-driven increments.

Motivation for a Standard SoS WBS. When trying to decide what should be included in a WBS, it is important to understand the various program needs to be addressed by the WBS. Typically, WBSs support program management planning and measurement needs, as well as technical needs. Program management uses the WBS to plan and measure progress. Therefore, the WBS must be at a level low enough to track the capabilities provided within each increment as well as planned capabilities that are moved to future increments for various reasons. This level of detail also supports the needs of the various technical teams and suppliers, allowing them to plan and track their efforts within the same framework as program management. What is needed to support today's SoS lifecycles is a WBS that captures the three basic components of the SoS development and operational environments:

- *Systems*: Needs to reflect the system components that comprise the SoS as well as the capabilities provided by each system component for each system increment.
- *Processes*: Needs to reflect the different processes used during the lifecycle: program management, agile assessments and planning, plan-driven implementation, and continual V&V across multiple overlapping increments.

- *People*: Needs to reflect the organization of the various teams, agile, plan-driven, and V&V, at the various SoS and supplier levels.

Current standard WBS templates seldom reflect all three components throughout the full lifecycle of the system of interest. Traditionally, program/project management has focused on a single system and its performance, with a build-to-spec, requirements-driven, waterfall perspective, and with little attention to the overall enterprise context or Operations and Maintenance (O&M).

A SoS WBS needs to be flexible and adaptable to respond to the evolutionary nature of the SoS lifecycle. It also needs to integrate systems engineering and programmatic aspects horizontally, and the systems and enterprises they support vertically. Through this type of organizational structure, there is a solid basis for cost estimation and tracking, proactively managing changing and competing priorities, supporting emerging capabilities, as well as addressing the longer-term issues with the use, ownership, and the governing agency of the SoS.

Goals and Scope. The goal of the research effort documented in this paper is to leverage leading developments in net-centric SoS systems engineering and processes, e.g., spiral development processes, capability-based acquisition process, and capability planning and investment analysis practices, and associated lessons learned to develop a tailorable and adaptable WBS model for future SoS lifecycle efforts. The intent is to provide a:

- Standardized, yet flexible, prototypical WBS for net-centric SoS engineering and management programs that can be used as a standard template to develop program-specific WBSs
- Reference model for SoS program management, systems engineering and cost estimating
- Full SoS lifecycle "cradle-to-grave" support using a systematic and holistic approach
- Framework to support analysis for decision making
- Compendium of commonly accepted SoS-related definitions.

FOUNDATIONS AND ASSUMPTIONS

Some definitions are necessary to set the context. A *mission* is a particular task given to a person or enterprise to carry out. Associated with a mission are goals and objectives. Together, they are the very foundation for the existence of an enterprise. At the tactical level, a *course of action* (COA), often embodied in an operational plan, is a sequence of operational activities that can be executed to support and accomplish the mission. A *capability*, or operational capability, is defined as the ability to execute a collective set of specified COAs necessary to accomplish the overall mission. The notion of capability embodies the systems, tools, people, and skill set to operate the systems, concept of operation (CONOPS), processes and organizations that enable the people and operation and sustainment of the systems.

THE WORK BREAKDOWN STRUCTURE

The proposed Work Breakdown Structure represents a prototypical SoS or FoS program. As a combined operational and acquisition entity, the program has an overarching mission and a set of initiatives of acquiring and evolving the operational capabilities to support the mission goals. It is generally initiated, funded and managed by a Government organization, under a Government-designated program manager (PM).

A generic product-oriented WBS construct for system development projects has been previously suggested (Ruskin 2004). It decomposes a final delivered system to elements that are

required to build the system over its development lifecycle. The structure is recursive in nature dividing the system into subsystems, subsystems into sub-subsystems, etc, and the general ingredients repeat at each level, scaled to smaller components. It is a fairly comprehensive structure describing the development or acquisition of a single system. Our proposed SoS WBS is based on the similar product-oriented structure. By the word "product", we mean any final and intermediate results that are produced, used, and consequently part of the SoS program during at least a part of its lifecycle. This may include physical systems – either in development or operation, design documents, process documents, architectural artifacts, organizations, and provided services and functions. These "products" are typically the end results of some processes and/or activities involved in the lifecycle of the SoS.

In terms of hierarchy, the WBS begins with one element at level 0; the SoS Program. It branches out into five elements at the next level (level 1); the **SoS in Operation**, **Spiral Alpha**, **Spiral Bravo**, **Spiral Charlie**, and the **Program Office**[1]. See Figure 2. The three spirals - Alpha, Bravo and Charlie - present the current and future acquisition cycles as discussed in the previous section. The elements at level 1 are further broken down into level 2, and so on, with each level containing an additional layer of detail as shown in Figure 3.
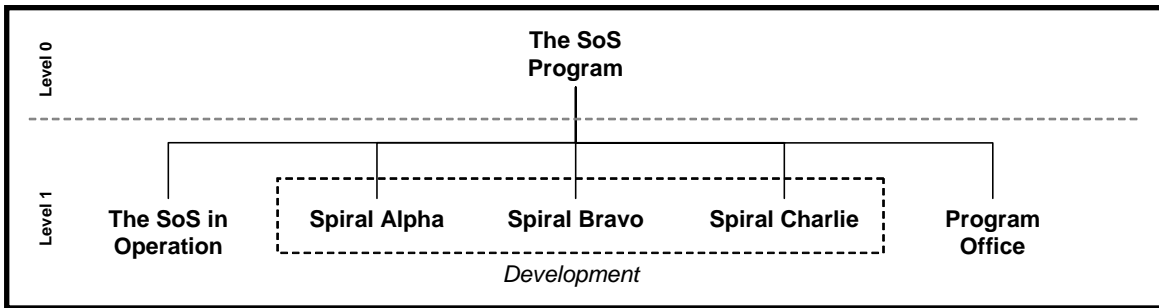

Figure 2. Prototypical top-level work breakdown structure for an SoS program

SoS in Operation – Legacy Systems

The *SoS in Operation* consists of the legacy systems that are currently fielded and the organizations that support these legacy systems in day-to-day operations. From the capability evolution perspective, it is operated under the as-is doctrine, CONOPS, and operational framework. It represents the mature technologies, dated CONOPS, and inadequate process support. In terms of interoperability, the systems within are generally stove piped, a mold set by the acquisitions of these systems, which were not intended to be interoperable with each other. The *SoS in Operation* is the source of the acquisition requirements for new and improved operational capabilities. It provides the baseline for capability analysis and the business case for new acquisitions.

The WBS in Figure 3 shows the future breakdown of this element. It presents a holistic view of the operational infrastructure, which includes the physical systems, organizations (the people), communications, support services, as well as the informational and programmatic products that are the basis of the command and control for the operations. At level 2 from left to right, the **Operational Plans** are a set of informational products specifying the planned COAs for the operation.

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[1]For the purpose of this paper, the prototypical program includes both operation and acquisition components under the same program management structure, even though many real-world programs segregate the two.
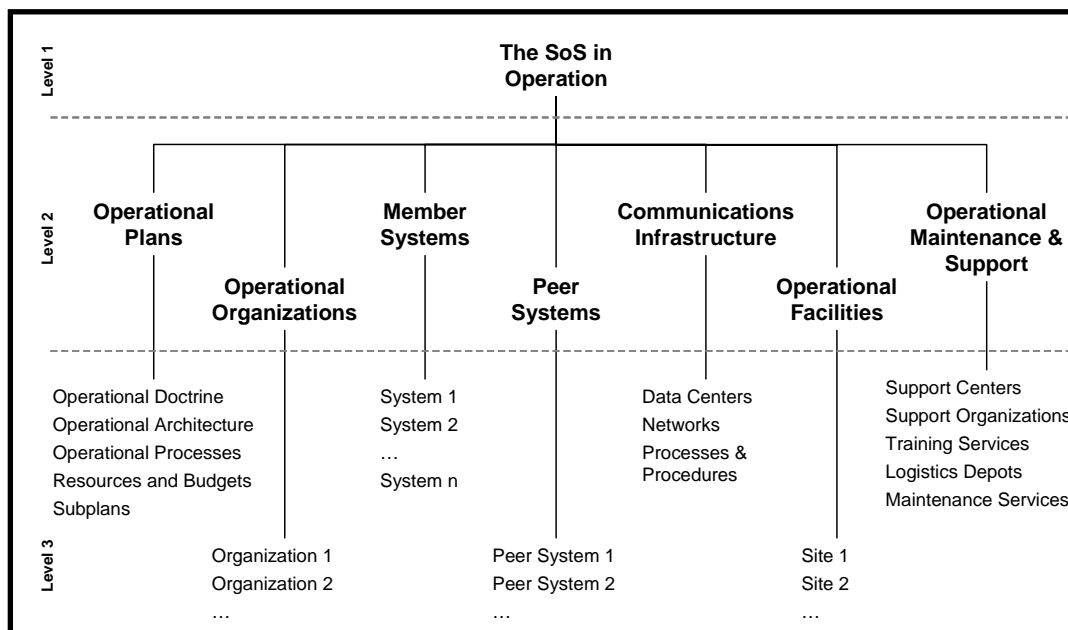
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Level 1                          The SoS in
                                  Operation

Level 2     Operational        Member          Communications      Operational
            Plans              Systems         Infrastructure      Maintenance &
                                                                   Support
                    Operational          Peer              Operational
                    Organizations        Systems           Facilities

         Operational Doctrine      System 1        Data Centers       Support Centers
         Operational Architecture  System 2        Networks           Support Organizations
         Operational Processes     …               Processes &        Training Services
         Resources and Budgets     System n        Procedures         Logistics Depots
         Subplans                                                     Maintenance Services

Level 3          Organization 1        Peer System 1        Site 1
                 Organization 2        Peer System 2        Site 2
                 …                     …                    …
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Figure 3. The SoS in Operation and the legacy capabilities

They are further broken down into elements at level 3 that include:

- **Operational Doctrine:** represents the set of principles and tenets of the operational framework. It should be noted that the SoS program or its operational arm may not have an unique set of doctrine documents, as it may not have the policy setting authority. The doctrine may be adopted from a higher level enterprise or program mission.
- **Operational Architecture:** a set of architectural products describing the CONOPS, scenarios, tasks and activities, and operational interfaces and protocols of the systems and organizations in the family.
- **Operational Process:** capture the processes and procedures for the operations. These documents are often closely related to the architecture documents, but more focused on step-by-step instructions.
- **Resources and Budgets:** operational budget requests, cost estimation, financial plans, schedule plans, and personnel assignments. Budgets are significant aspect of most program plans, so they are singled out into a separate category.
- **Subplans:** all other planning aspects of the operations. Collectively, they comprise the core of the overall operational framework. The elements typically include staffing plan, logistic and supply management plan, configuration management plan, mission assurance plan, risk management plan, training plans, reporting plans, review plans, and control and authorization plans.

The next level-2 elements are the *Operational Organizations*. They represent the end user or operators of the SoS. Mechanically, the element represents an organization chart.

The next two elements are the *Member Systems* and the *Peer Systems* in the SoS. These are the individual and independent systems that have been designed and built to perform a unique

and complete functionality[2]. In the SoS mission, they are to interoperate with each other to achieve collective operational effects, unattainable by the individual systems operating on their own. The member systems are those systems under the direct command and control of this SoS program. The peer systems are integral part of the SoS operation. However, they are under different governance models or separate budgetary authorities. This program office has no direct mandate and authority over their operation and evolution. It must rely on negotiation and collaboration to satisfy its own interoperability requirements. DoD examples of peer systems include strategic assets such as satellites, communications nodes, command structures under different branches, or intelligence functions.

The element that follows is the *Communications Infrastructure*. It encompasses the communications network, data centers (including the servers and storage), and processes and procedures that support communications capability. We should bear in mind that this infrastructure today may rely on human intervention to bridge the technological gaps.

The next element at this level encompasses the *Operational Facilities*, which are organized according to graphical locations. It is followed by the *Operational Maintenance and Support* functions, which includes five elements at the next level: *Support Centers* (e.g., Call Center, Help Desks), *Support Organizations* (e.g., external organizations that have the support contract), *Training Services* (responsible for operational readiness training), *Logistic Depots* (which include spare parts and consumables at the next level breakdown), and *Maintenance Services* (including labors and materials).

The *SoS in Operation* is an operation and maintenance centric structure. It captures the existing capability with as-is CONOPS and architecture, mature and sometimes outdated technologies, and often very limited interoperability. Driven by new threats or emerging operational needs, the systems and the people are adapting in an ad hoc manner, learning new behaviors from practice and adjusting new environments that they are unprepared to operate in. However, it sets the baseline for architecture improvement and business case analysis. It is the source of the new acquisition requirements.

Spiral Alpha – Current Acquisition Effort

This is the acquisition spiral for major capability upgrade. It is by nature a project - even thought it is often called program in practice due to the magnitude and budget involved - with definitive start and end dates, a relatively stable set of requirements, and projected deliverables stipulated by various contractual agreements. The plan-driven team manages the project, and IV&V Team is responsible for the verification and validation of the deliverables. Figure 4 depicts the WBS for the project, which consists of ten major elements at level 2. The detail of each element is discussed next.

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[2] In today's SoS, there are instances of functional duplications and overlaps, a companion problem with functional gaps, a result of legacy acquisition approaches.
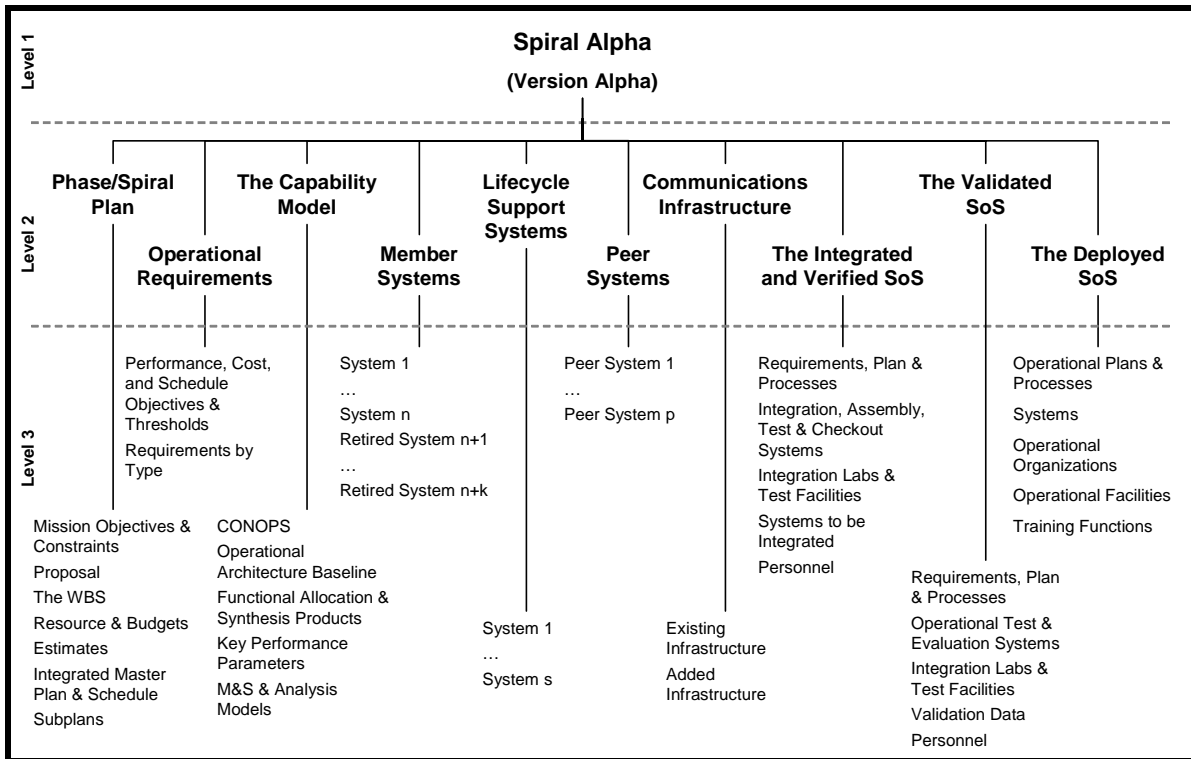
Spiral Alpha

(Version Alpha)

Level 2	Level 3
Phase/Spiral Plan	Mission Objectives & Constraints; Proposal; The WBS; Resource & Budgets; Estimates; Integrated Master Plan & Schedule; Subplans
Operational Requirements	Performance, Cost, and Schedule Objectives & Thresholds; Requirements by Type
The Capability Model	CONOPS; Operational Architecture Baseline; Functional Allocation & Synthesis Products; Key Performance Parameters; M&S & Analysis Models
Member Systems	System 1 … System n; Retired System n+1 … Retired System n+k; System 1 … System s
Lifecycle Support Systems	
Peer Systems	Peer System 1 … Peer System p
Communications Infrastructure	Existing Infrastructure; Added Infrastructure
The Integrated and Verified SoS	Requirements, Plan & Processes; Integration, Assembly, Test & Checkout Systems; Integration Labs & Test Facilities; Systems to be Integrated; Personnel
The Validated SoS	Requirements, Plan & Processes; Operational Test & Evaluation Systems; Integration Labs & Test Facilities; Validation Data; Personnel
The Deployed SoS	Operational Plans & Processes; Systems; Operational Organizations; Operational Facilities; Training Functions

Figure 4. Spiral Alpha - the current acquisition spiral

Phase/Spiral Plan. The first element is the phase or spiral plan for the project. It is a prototypical project plan for an acquisition initiative. It comprises the following elements at level 3:

- **Mission Objectives and Constraints.** The project is a mission in its own right. This element contains the documentation of the initial mission objectives and subsequent updates to them. Any constraints for the project are also recorded here.
- **Proposal.** This element contains the project proposal, Request for Proposal (RFP), and suppliers' or bidders' technical proposals. It may also contain an unofficial reference to the contract award documents, which are generally under the purview of program's contract and legal function at the higher level (see the Program Office WBS element).
- **Work Breakdown Structure.** The spiral plan also includes the detailed project WBS. This is a circular reference to the structure itself. It is important to know that this WBS will go through a progressive refinement process and will grow as the project planning matures.
- **Resources and Budgets.** This element contains the project financial budget plans and resource profiles. Also included in this category are personnel lists and bill of materials.
- **Estimates.** This element includes the cost, effort and schedule estimates that are the basis for the resource and budget plans.
- **Integrated Master Plan and Integrated Master Schedule.** All projects today have an integrated master plan and an associated integrated master schedule.
- **Subplans[3].** These documents describe various aspects of conducting and managing a

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[3] Not to be confused with the sub plans for operations as discussed above, these plans are for development and acquisition purposes.

project. They are typically organized according to project control functions. Examples include staffing plan, work authorization plan, project control plan, requirement change plan, configuration management plan, quality assurance plan, risk management plan, project review plan, etc.

Operational Requirements. The second element at level 2 is the operational requirements. The word "operational" indicates that these requirements are in terms of operational capabilities, rather than system functionality as is often the case for system acquisitions. Included in this category are the performance, cost, and schedule objectives and thresholds. The detail requirements can be arranged in different organizations – by systems or components, by source, or by type. Examples of Requirements by Types include functional requirements, performance requirements, -Ility requirements, interface requirements, verification and validation requirements, resource requirements, review requirements, etc.

The Capability Model. The operational architecture and analysis model serve as the basic architecture design for the capabilities to be delivered. It serves the same purpose as the system design documentation for development of a system. It is the SoS counterpart, and the model and its components focus on the description of the operational capability. The next level of the WBS holds the artifacts of this integrated model, including:

- **Concept of Operations (CONOPS).** It is a general description of the operational scenarios and engagement rules.
- **Operational Architecture Baseline.** It describes the operational activities, the systems structure and interfaces. The baseline specifies the capability deliverables of the spiral and should stay relatively stable throughout the project lifecycle.
- **Functional Allocation and Synthesis Products.** Unlike system-level design efforts, the SoS design activities center around function allocation and synthesis activities through techniques commonly known as gap and overlap analysis. A significant part of this effort is the capability-level design trades, cost-benefit and Return On Investment (ROI) analyses. This element holds these architecture analysis products.
- **Key Performance Parameters (KPPs).** Similarly, these are operational level KPPs, as opposed to system performance level parameters.
- **Modeling, Simulation and Analysis Models.** Various M&S models are necessary to complement the operational architecture baseline and provide more insights into the desired capability level. These models can be static, such as in DoDAF or Zachman, or dynamic in nature and may involve variety of simulation tools.

Member Systems. These are typically the main targets of the acquisition initiative and constitute the majority of the material deliverables in the spiral. They include those member systems within the SoS that will be changed in some form in order to achieve improved capabilities, either through new acquisition or upgrade of the legacy systems. As the result of capability upgrade, some legacy systems may be retired and disposed. Efforts are required for decommissioning and retiring these systems. In addition, changes may be required in terms of interfaces and interdependencies of other systems.

Peer Systems. As we mentioned before, these systems are under the direct command and control of different organizations but are integral part of the interoperability of this SoS. They appear in this WBS because either 1) they have changed on their own and, as the consequence, the member systems must change to adapt, or 2) reversely the interfaces with these systems must

change as the result of changes occurred in the member systems.

Lifecycle Support Systems. These are the systems that complement the Member Systems and Peer Systems in operation but not necessarily contribute directly to the operations of the SoS.

Communications Infrastructure. This is part of the communications infrastructure that must be changed due to the capability upgrade. It may include systems, networks, personnel and processes related to supporting the communications functions of the SoS[4].

Integrated and Verified SoS. Once the member systems and other components of the SoS are acquired, they must be integrated into an SoS and the result must be verified against the requirements. This element includes products required for integration and verification activities, including Integration, Assembly, Test and Checkout (IATC) requirements and plans, IATC systems, integration labs and test facilities, the systems to be integrated, and the system integration personnel.

Validated SoS. This element includes products required for validation and operational readiness tests of the SoS. The subcomponents under this branch of the WBS should be self-explanatory.

Deployed SoS. This element represents the final delivery of the spiral – the incremental SoS capability as an *integrated system* – and is a snapshot of what is transitioned to field operation. Most of the sub-elements under this element overlap with those under the SoS in Operation, however, they capture the changes to these aspects as the result of this acquisition delivery.

As indicated before, Spiral Alpha's objective is to acquire operational capability, rather than system performance. The WBS consequently captures the elements of high-level functionality, focusing on design activities related to functional allocation and synthesis, rather than engineering details. It treats all systems as generic systems and emphasizes on COTS integration. The WBS is targeted for post-concept development/DoD milestone A and pre-prototype/DoD milestone B phase entrance. The deliverables will become the new "as-is" baseline for the SoS in Operation.

Spirals Bravo and Charlie – Future Capability Increments

Spirals Bravo and Charlie are the future acquisition spirals in time. As previously mentioned, there are typical partial overlaps between all three spirals – as Alpha is full force, Bravo is in planning and Charlie may be in concept. The general notion is that Spiral Alpha executes for a finite period of time and as it comes to a closure, Spiral Bravo spins up and becomes the next acquisition spiral and Charlie becomes the next Bravo, and so on. As such, the work breakdown structures for Spirals Bravo and Charlie are virtually identical to the first three elements of the Spiral Alpha's WBS at level 2, which are predominately early informational products, as shown in Figure 5. The only difference is in the level of detail and elaboration. While the plans, requirements and capability models for Spiral Alpha are stable and extensive, they are less detailed, often spotty, and more volatile for Bravo and even more so for Charlie. The sources of the material are from the drop-offs of Alpha's priority list due to budget and resource constraints, evolving user needs, emerging applications, changing environment or threats, new technologies, and lessons learned from the current acquisition experience.

Spiral Bravo may support significant modelling and simulation and experiment activities. It

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[4] If the main objective of the spiral is to upgrade communications infrastructure, elements of the infrastructure can be re-categorized under the member systems.

may support small off-shoot prototyping type of programs. However, the major objective and deliverable, if any, is to focus on establishing future acquisition requirement and supporting architectural models. When Spiral Bravo becomes the future acquisition spiral, this WBS becomes the baseline of the then-Alpha WBS, which is elaborated into the full-fledged structure as in Figure 5.

The Spiral B's and C's WBSs are the main responsibility of the Agile Rebaselining Team. It will work in tandem with the Plan-driven Team that is concurrently working on Spiral A, identifying and prioritizing future trends and needs. The Agile Team may, at the same time, take on the overall program chief architect role overseeing the full program lifecycle.
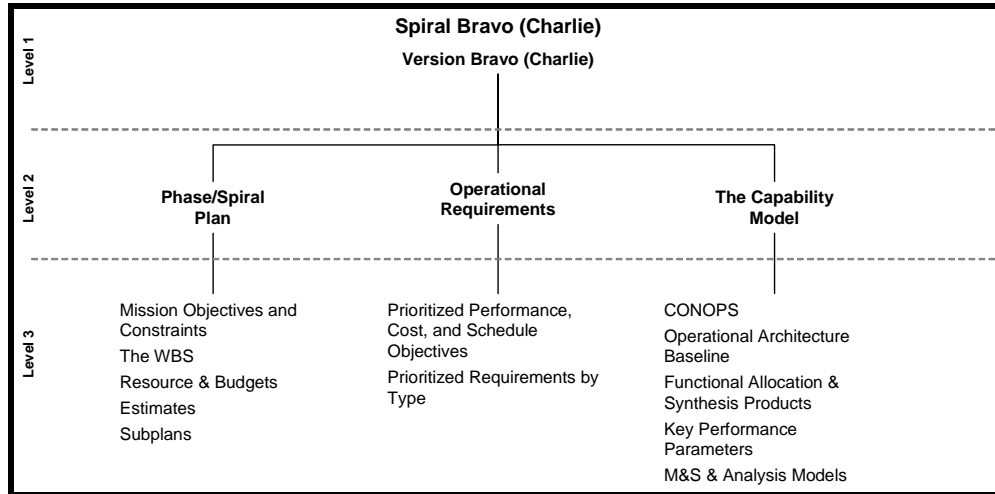

Figure 5. WBS for Spirals Bravo and Charlie

SoS Program Office – the Supporting Enterprise

The Program Office is the supporting enterprise for the entire SoS program. It provides the lifecycle planning, management and oversight roles to ensure the successfully operation and evolution of the capabilities. It also provides budgetary and organizational support to the operation and acquisition initiatives to ensure that adequate resources are requested and applied. In the DoD terms, it encompasses the Doctrinal, Organizational, Training, Materiel, Leadership, Personnel and Facilities (DOTMLPF) aspects of the enterprise. It manages the three project teams: Plan-driven, IV&V and Agile. Figure 6 depicts the prototypical WBS.

The Program Mission. As any enterprise, the program has its mission and lifecycle objectives. The program mission statement, goals and objectives and other doctrine and policy documents establish the foundation for the program's day-to-day operations, which are part of the first element for the program office WBS.

The Capability Models. The second element contains a series of operational and architectural products that underlies the basis for the evolution of lifecycle capabilities and acquisition strategies. The models can generally be divided into two groups, represented by the two elements at level 3:

- **Capability Needs Documents**, which summarized all the capability needs from the operational perspective. The Joint Capabilities Integration and Development System (JCIDS) process specifies four documents for developing and communicating the

capability needs: joint capabilities document (JCD), initial capabilities document (ICD), capability development document (CDD), and capability production document (CPD).

- **Lifecycle Architecture Products**. These are the integrated architecture product similar to those in the Capability Model element of the Spiral Alpha WBS but with a program lifecycle focus. In addition, it includes the capability development roadmap documents depicting the planned evolution path.

The Program Plan. This element aggregates all program-level planning documents. Most of the sub-elements should be self-explanatory and, once again, as a part of the plan it contains a circular reference to the WBS itself. An added element at level 3 includes the **Business Case Documents** which provide business case analyses, investment strategies and ROI analyses for the purpose of program funding justifications.

Suboffices. This is basically the organization chart for the program office. The organizations should be self-explanatory. It should be noted, however, that depending up the type of program, there may or may not be an actual office for each of the functions. They can be part of the offices in the parent organization. Nevertheless, the services they provide should be accounted for within this program office.

Stakeholder Group. Stakeholders are key part of the enterprise and critical for the mission success. The governance problem represents one of the central issues with SoS and FoS in general. The last WBS element encapsulates all the members of the stakeholder community for the program who have a vested interest in its mission and capabilities. Represented by the elements at level 3, the group includes the SoS **Program Manager** (PM), the **End Users** of the SoS, the **Lead System Integrator(s)** – generally an industry partner for the program - the **System Suppliers** and their **Participating Acquisition Resource Managers (PARMs)**, technology **Labs**, **Peer Program Offices** that are responsible for the acquisition of the peer systems within the SoS, and the **Operations Offices** that are often in direct charge of the systems in operations within the SoS. There is sometimes a need of a liaison function (or personnel) in the PM office that coordinates the communications and participation of the stakeholders.
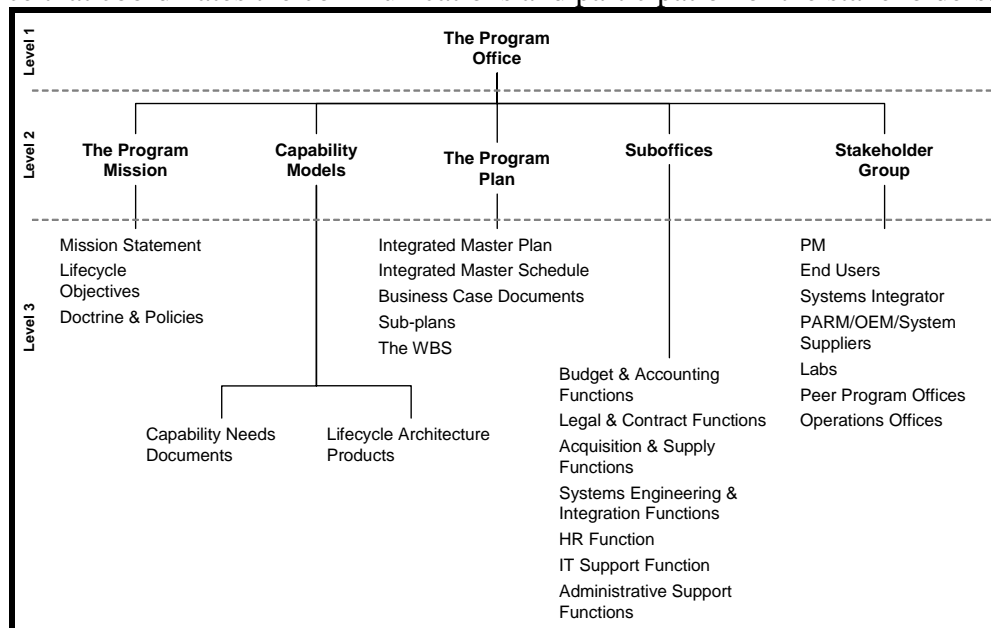

Figure 6. The SoS Program Office - the supporting enterprise

Implementation Implications

This WBS is designed to support incremental acquisition of operational capabilities. It is based on the lifecycle perspective and an assumption of an evolutionary process and a spiral development model. These concepts are relatively new to the acquisition communities, particularly with those large and complex systems, to which the SoS engineering and management theory is relevant. The model requires new thinking and forward-looking vision. This undoubtedly puts a pressure on the acquisition managers and chief architects, who have been trained in the transitional "build-to-spec" acquisition model. It calls for a new set of skills. It also invites a transformation of the existing contract and program incentive structure to better endorse the new acquisition model.

This WBS is a relatively high level one. As the tree branches grow, they will interact with the WBSs for individual systems. In fact, the structure is designed to easily integrate standard, system-level WBS constructs at the lower levels.

Technically, the product-oriented WBS emphasizes on "products". With SoS type of programs, significant efforts are in the processes and activities. There needs to be a consistent match between the activities and the products they yield, so that all processes and activities are accounted for in the WBS. Additionally, most of the terminologies used are adopted from developing a system. However, in the SoS context, many have significantly different biases. To support the extension of system context to the SoS context, there is a need for a refined set of unambiguous terms that are consistent in both communities. We continue the pursuit of this common taxonomy as we validate our approach in practice.

CONCLUSION

As the role of the Lead Systems Integrator continues to be defined, the SoS Statement of Work will continue to be clarified. Advancing these concepts will provide the systems engineering community with several benefits:

- It provides a reference model for SoS/FoS engineering and management. Since no two SoS' are exactly the same or contain the same exact elements, this WBS can provide a checklist function for engineering and program management considerations.
- It defines a common set of terminology related to SoS - with a favorable bias towards the military/DoD domain - which is a constant struggle even amongst the domain experts.
- It enables visibilities and insights into unique issues related to SoS, such as interoperability, interdependency, organizations and ownership, conflict management, and the decision framework.
- It provides a holistic view for SoS engineering and program management.

Most importantly, this work provides a platform for dialog amongst systems engineering researchers and practitioners. Furthermore, it enables the understanding of the effort and cost involved with acquiring and owning such a SoS and the methodology that can be applied to estimate them.

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