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Managing Complex Systems Engineering and Acquisition Through Lead Systems Integration

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Abstract

In the modern operational environment, multiple systems forming System of Systems (SoS) are required to satisfy the spectrum of capabilities needed to satisfy the mission. Accomplishing the mission has always been a SoS endeavor, where integrating multiple systems into a SoS has been left to small communities of "hero engineers," or to the operators responsible for the mission. The acquisition and management of these mission capabilities across the SoS life cycle requires the complex integration of interdependent new and legacy systems from the lowest component level to the highest enterprise level. In 2008, Congress directed government organizations to adopt a Lead System Integration (LSI) process to address the issues with the acquisition, development, and integration of a SoS. The purpose of this paper is twofold: (1) the results of our early exploration of LSI are presented with the definition and development of the LSI Enterprise Framework; (2) it provides an update to our ongoing research that is using a model-based approach to explore the correlation between other frameworks and processes used to engineer and manage SoS employed by Navy Systems Commands.

Introduction

In 2008, Congress enacted Public Law 110-181, directing the Secretary of Defense to properly size and develop the government acquisition workforce to accomplish inherently governmental functions related to the acquisition of major defense systems and to minimize, and eventually eliminate, the use of industry-performed Lead Systems Integration (LSI) functions. Lead Systems Integration is an acquisition strategy that employs a series of methods, practices, and principles to increase the span of both management and engineering acquisition authority and control to acquire system of system (SoS), or highly complex systems (NPS-NAVAIR LSI Cohort #2, 2015). The roles of the LSI are similar to the traditional roles performed by systems engineers and systems integrators. The primary difference is the span of design and integration authority that persists throughout SoS acquisition and life cycle.

The Navy explored the LSI concept and provided a draft implementation plan shortly after the Congressional mandate. Although the Navy did not immediately implement the LSI recommendations, they did pursue processes to engineer and manage SoS. Frameworks such as Information Technology Technical Authority (IT TA) and Integration and Interoperability (I&I) have dominated the SoS process discussion for the better part of a decade. In recent years, the Naval Air Systems Command (NAVAIR) has revitalized LSI and has been striving to better define and implement the concept. While each framework has its strengths, none solely addresses the complete problem.

The purpose of this paper is twofold. First, the results from our early exploration of LSI are presented, with our definition and development of the LSI Enterprise Framework. This framework is a means by which the government can engineer and manage the capabilities and interdependencies of a SoS, across multiple systems, programs, and stakeholder levels.

Second, this paper provides an update to our ongoing research that uses a model-based approach to explore the correlation between IT TA, I&I, LSI, and other frameworks used to engineer and manage SoS employed by Navy Systems Commands. The premise is that by identifying the strengths of each, a revised framework to improve the engineering and management of SoS can be suggested.

The LSI Enterprise Framework Levels

The LSI's purpose is to affordably optimize integrated mission capabilities across the SoS life cycle (NPS-NAVAIR LSI Cohort #1, 2014). To successfully plan, develop, and manage a SoS, a comprehensive development, acquisition, and implementation strategy is required. The LSI Enterprise Framework captures the complex, interdependent, and mission capability areas to characterize the systems from the enterprise to the component levels. This framework establishes the means to engineer and manage the capabilities and interdependencies of a SoS, or complex systems, that can be executed by the government LSI, across multiple systems, programs, and stakeholder levels, where operational and managerial interdependencies exist. The foundation of the LSI Enterprise Framework are the four levels of programs, systems, and stakeholders. The LSI interfaces between the different boundary layers in Figure 1 (NPS-NAVAIR LSI Cohort #2, 2015).

Enterprise Capability Level

The Enterprise Capability Level is the top layer of the LSI framework that consists of a variety of stakeholders, from one or many organizations that represent the complex, sociotechnical systems that comprise interdependent resources of people, information, and systems that must interact with each other and their environment to achieve mission success (Giachetti, 2010). While the majority of the LSI engineering and management activities occur below the enterprise level, this level is important because this is where organizational, policy, and resource decisions are made that provide guidance and governance throughout all levels of the enterprise. It is at this level where the capabilities required to achieve enterprise mission success are defined, decomposed, and allocated to the SoS level to be satisfied as mission capabilities.

Mission Wholeness Level

The Mission Wholeness Level is where a collection of supporting constituent systems and programs are brought together into a SoS to support end-to-end capability effectiveness for the designated mission areas. A SoS is a set or arrangement of systems when independent, and task-oriented systems are integrated into a larger systems construct, that delivers unique capabilities and functions in support of missions that cannot be achieved by individual systems alone (Vaneman & Budka, 2013).

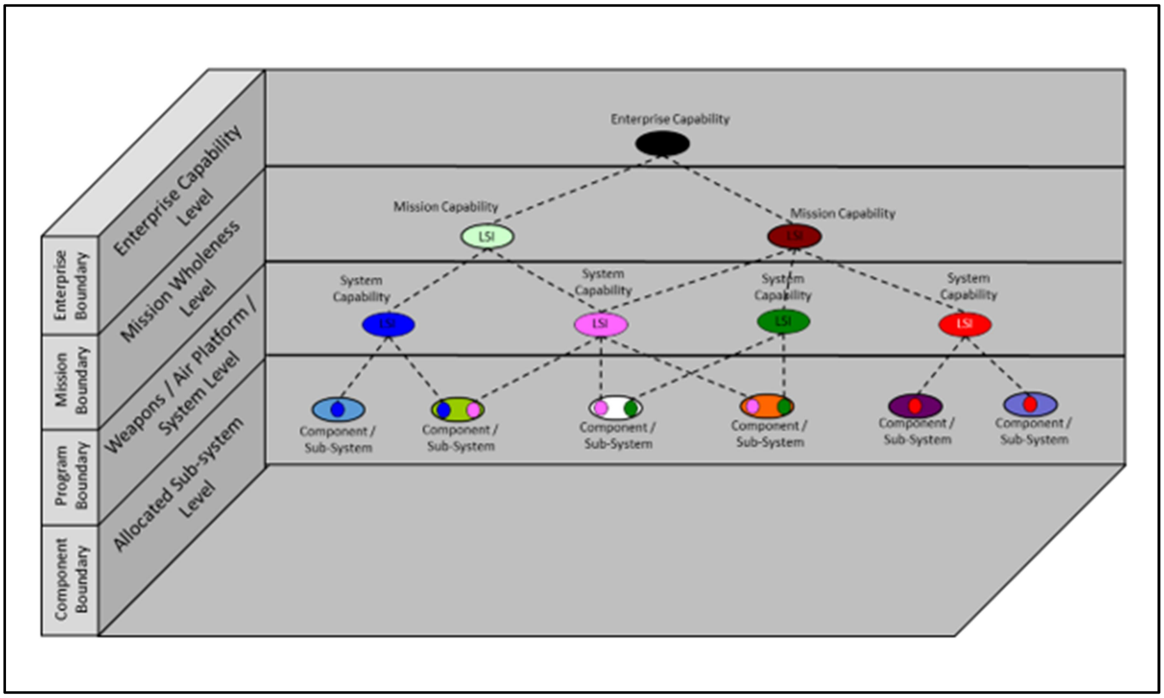

Figure 1. Four Levels of the LSI Enterprise Framework

Accomplishing mission capabilities has always been a SoS endeavor. However, knitting the multiple systems together has frequently been left to small communities of systems or to the operators themselves. The LSI adds the rigor and discipline into combining constituent systems into a SoS, thus reducing the risks that happenstance or chance introduces when integration is left to the operator. Examples of defense mission areas include ballistic missile defense, antisubmarine warfare, counter-air warfare, and surface warfare.

Many of the LSI activities are similar to traditional systems engineering, systems integration, and program management functions. These activities are expanded at the Mission Wholeness Level and are described by those functions encompassed by System of Systems Engineering and Integration (SoSE&I). System of Systems Engineering and Integration is the planning, analyzing, and integrating constituent systems into an SoS capability greater than the sum of those systems (Vaneman & Budka, 2013). The LSI uses the functions defined within SoSE&I to put systems engineering and program management rigor and discipline into development, acquisition, and sustainment decisions at the Mission Wholeness Level. The key elements of SoSE&I are as follows:

1. Managed SoS baseline that directly tracks to mission capabilities;
2. SoS validation, verification, and certification methodology to evaluate delivered capabilities in the context of mission performance;
3. Formal method of governance and change control that puts discipline and rigor into investment decisions at the SoS Level.
   (Vaneman, 2016)

Systems Level

The System Level is where a combination of functionally related physical elements are integrated into a usable system to achieve a capability. The systems developed and acquired at this level can operate independently. Examples of systems within the aviation community include different types of aircraft.

Traditional development, sustainment, and management of individual systems is the emphasis of the System Level. The goal of the LSI is to best influence and impact SoS opportunities, and design flexibility into these constituent systems to best adapt to new interfaces, thus extending functionality of the SoS. Three significant roles are important to the LSI in this level. First, the LSI must ensure that the SoS level organization has sufficient insight and understanding of the individual programs and constituent systems within the SoS to understand the functionality, interoperability, and compatibility that will result from the engineering and design effort. This role is important because as decisions are made within program offices to optimize individual systems, they are often made without consideration of the system within a SoS (Vaneman, 2016).

Second, understanding constituent system functionality and programmatic issues is critical since constituent systems in a SoS rely on each other to achieve mission success. Issues such as system schedule delays or technology issues leading to capability shortfalls are critical since other systems that depend on upstream information may not be able to fulfill their missions within a SoS. System retirements are also an area of concern because a premature decommissioning may yield gaps that inhibit the SoS (Vaneman, 2016).

Third, the LSI must ensure a strong governance model is in place that provides the technical authority to govern system baselines so that the system delivered for integration into a SoS meets the requirements that were allocated to it (Vaneman 2016).

Allocated Subsystems Level

The Subsystem/Component Level consists of the allocated sub-systems and components that by themselves may or may not provide a usable standalone end product or capability. These are the lowest level building blocks required for any SoS or complex system that are typically managed by a team in a larger program office or separately by subsystem program offices for large and complex subsystems (Vaneman & Carlson, 2017). Examples of subsystems within an aircraft include avionics, propulsion, and communications.

The LSI Touchpoints

Given the breadth of a SoS acquisition effort and recognizing that a government LSI's resources to manage an effort are limited, an LSI must be able to efficiently focus on the highest payoff "touchpoints" of control or influence to assert and execute trade space—aligned across the enterprise—to enable organizational agility. Although previous efforts have discussed the inherently governmental functions for an LSI, there has been unclear guidance to current program processes (U.S. Navy Chief Systems Engineer, 2010).

The LSI Enterprise Framework defines 12 key touchpoints that apply across all domains as the essential "high payoff" functions and activities. These LSI touchpoints are the functions that implement trade spaces to affordably optimize integrated warfighting capabilities across the SoS life cycle. These touchpoints do not necessarily define new processes but do identify how existing processes can be enhanced and used more efficiently. Figure 2 depicts the traditional organizational and programmatic functions and the 12 touchpoints required for a LSI (NPS-NAVAIR LSI Cohort #2, 2015).

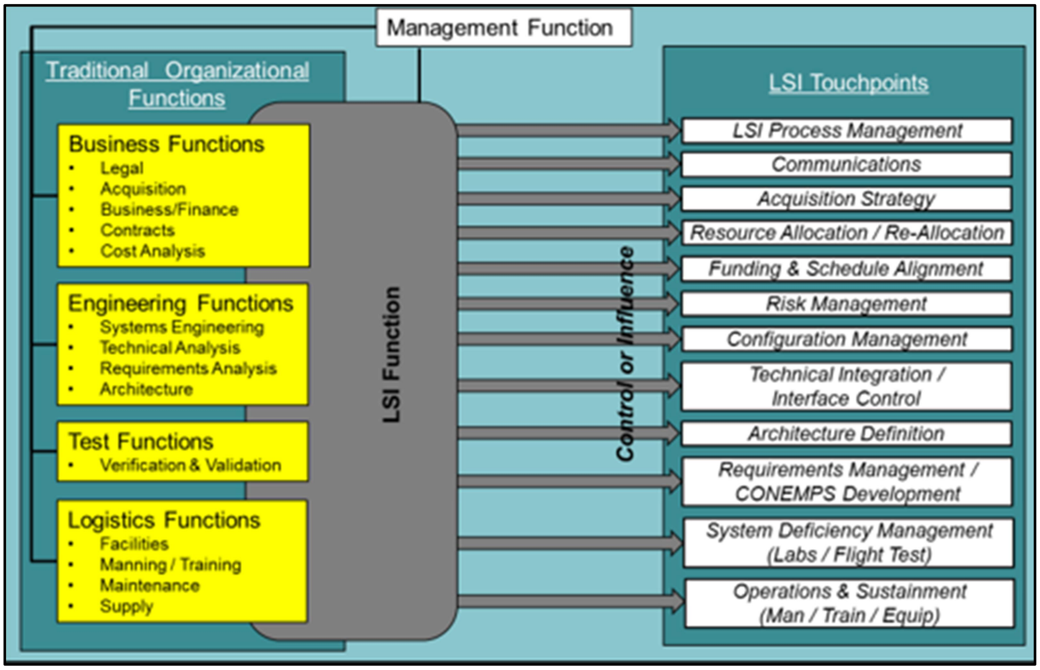

Figure 2. Traditional Organizational Functions and the LSI Touchpoints

LSI Process Management

Responsible for mission wholeness, the LSI defines how their processes interface and interact with legacy processes across multiple stakeholders to meet unique SoS mission capabilities and trade space objectives. These standard work processes document the most efficient known method to produce a system or service, eliminating procedural waste and establishing a baseline for future process improvement initiatives. Standard work packages define process trigger conditions, objectives, enabling factors, inputs, functions, outputs, interfaces, and process time. Furthermore, these standard work processes are the foundation of effects-based staffing, which is critical to defining the skills and resources required to build and maintain an acquisition workforce capable of executing an LSI acquisition strategy (NPS-NAVAIR LSI Cohort #2, 2015).

Communication

The LSI serves as the primary interface and facilitator across a diverse stakeholder constituency. The continuous evolution of SoS capabilities, priorities, mission environments, assumptions, constraints, and threats mandates unprecedented organizational alignment and enterprise agility. Due to the number of typically "stove-piped" teams and program offices, the need to communicate effectively is a key to success. The desired end state of this communication touchpoint is full programmatic, technical, and organizational alignment between the LSI acquisition objectives, and the objectives of the constituent systems (NPS-NAVAIR LSI Cohort #2, 2015).

Acquisition Strategy

The LSI should serve as the principal SoS acquisition strategist. While the U.S. government has been assembling SoS for decades, there is often no overarching acquisition strategy. Given their broad responsibilities, the LSI is often in the best position to develop an overarching acquisition strategy that can be implemented across multiple independent and asynchronous programs and stakeholders to achieve the desired mission capabilities within the resource constraints (NPS-NAVAIR LSI Cohort #2, 2015).

Resource Allocation/Reallocation

The LSI is the primary arbitrator of enterprise resource allocations and reallocations between constituent SoS elements and stakeholders. Requirements and risk mitigation plans should be properly funded across the integrated mission architecture in accordance with an LSI value maximization strategy to achieve the desired capability outcomes. Given the inherent volatility, uncertainty, complexity, and ambiguity of SoS mission environments, allocation of requirements and resources is an iterative process that occurs throughout the mission life cycle (NPS-NAVAIR LSI Cohort #2, 2015).

SoS asynchronous development schedules add a new degree of complexity to LSI resource allocation and re-allocation functions. Given the broad scope of constituent systems encompassed within many SoS mission architectures, it is unlikely that all elements will be in the same acquisition phase. In order to optimize SoS mission value across the SoS trade space, the LSI should also consider the overall mission readiness throughout the SoS life cycle, including existing legacy operations and sustainment activities (Vaneman & Carlson, 2017).

Enterprise Funding and Schedule Alignment

The handling of funding is an inherently governmental function. Enterprise funding and schedule alignment is especially challenging for the LSI since resources are usually budgeted by the resource sponsors to specific programs and systems, and not the SoS to satisfy enterprise or mission-level capabilities. The LSI should be aware of dynamic funding and schedule changes across multiple programs and must align multiple asynchronous schedules of the constituent systems it may control (NPS-NAVAIR LSI Cohort #2, 2015).

System Deficiency Management

SoS deficiency management, supported by laboratory and operational verification and validation activities, is challenging for LSIs in complex mission environments involving multiple programs and stakeholders. The LSI should determine the impact of constituent systems deficiencies at the SoS level. The LSI should also determine the best way to mitigate these deficiencies. The use of simulations and prototypes representing each constituent system that comprises the SoS is a cost-effective method that can be used for early integration risk reduction and may help to refine requirements and identify additional requirements and constraints at the SoS level that may not be apparent at the system level (NPS-NAVAIR LSI Cohort #2, 2015).

Architecture Definition

An architectural definition for a SoS, preferably developed and hosted in a Model-Based Systems Engineering (MBSE) environment, is essential for engineering, analysis, and management of the SoS. The SoS architecture provides a technical blueprint of the SoS, showing the traceability of functional and derived relationships among all constituent systems. The architectural viewpoints enable stakeholders to visualize, define, and bound the component systems, SoS, and identify integration points both inside and outside the systems. From these views, system interoperability issues can be identified. With proper CM and use of compatible databases, new systems entering the SoS family may more easily integrate from an LSI standpoint, and where all disciplines can see integration impacts, dependencies, and interoperability concerns (NPS-NAVAIR LSI Cohort #2, 2015).

Requirements Management and Concepts of Employment

Once a preferred SoS concept is established, the LSI allocates requirements, functions, interfaces, and constraints across constituent systems. This task is especially challenging since the LSI must consider enterprise requirements management and concepts of employment (CONEMPS) across multiple systems and stakeholders. The stakeholders may each hold different assumptions, limitations, or constraints about the expected use of systems, and the mission requirements for the SoS. Constituent system decomposition and integration may also change dynamically or emerge during the evolution of the mission capabilities during SoS life cycle. Requirements management for the LSI is further complicated since the allocation of requirements and resources may be iterative and ongoing across elements that the LSI may not control. The LSI should align requirements, assumptions, limitations, and constraints at the capability level for the overall SoS effort. The CONEMPS may be used as one tool to energize early user and resource sponsor involvement to align stakeholders (NPS-NAVAIR LSI Cohort #2, 2015).

Configuration Management

Configuration management (CM) is the application of appropriate resources, processes, and tools to establish and maintain consistency between the system requirements, the system, and the associated system configuration information. This CM definition must be expanded to address the asynchronous CM across multiple interdependent stakeholders and constituent systems. This asynchronous CM is especially complex for a LSI that must establish and maintain the overall SoS CM baseline throughout the life cycles for all system baselines. Since multiple system program baselines contribute to mission success, the LSI’s CM baseline may change dynamically (NPS-NAVAIR LSI Cohort #2, 2015).

Technical Integration and Interface Control

Technical integration and interface control has a more significant role for the LSI bringing together a SoS, or complex system, than in traditional systems engineering. Since technical trade space management for a SoS occurs at the interfaces between constituent systems, the LSI should focus on enterprise technical integration and interface control. This effort is far more complicated than a traditional acquisition effort, since the technical maturity of the constituent systems within the SoS may be at different levels, and may also be changing at different rates (NPS-NAVAIR LSI Cohort #2, 2015).

Risk Management

Risk management for a SoS is more complex than for traditional systems. Since there are likely many interdependent stakeholders and constituent systems in this effort, the LSI should expand the traditional definition of risk management from the system level and focus on risks at the SoS level. LSI risk management must maintain visibility of risks and opportunities of all systems and critical subsystems, across the SoS trade space. The LSI defines alternative mitigation strategies to combine and normalize these risks across the SoS trade space (NPS-NAVAIR LSI Cohort #2, 2015).

Operations and Sustainment

The LSI’s challenge of affordably optimizing integrated system capabilities across the SoS life cycle is more complex than in a traditional acquisition effort since it may involve multiple independently-developed support strategies or existing legacy system support strategies across the systems in the SoS, which may also be at different levels of maturity. The LSI must understand the support requirements for the entire SoS so that the logistical requirements can be allocated effectively to the constituent systems and supporting stakeholders. The logistics support system should be evaluated across the SoS life cycle to ensure operational supportability with specific attention to minimizing the logistics footprint. Sustainment costs should also be considered during system development and evaluated during testing to ensure that when the SoS capability is fielded, the sustainment costs to support the system are within the constituent systems and/or the LSI's SoS budget (NPS-NAVAIR LSI Cohort #2, 2015).

The Stakeholder Architecture and Governance

The LSI is responsible for defining the enterprise stakeholders, their equities, interest, relationships, and possible impacts to the enterprise trade space to affordably optimize integrated warfighting capabilities across the SoS life cycle. These stakeholder capabilities are represented in an architecture that uses a mission-based, top-down approach to consider the systems from an end-to-end mission perspective (Vaneman, 2016). The LSI responsibilities apply horizontally across the operational, acquisition, and resources sponsor stakeholders within each LSI Enterprise level to ensure coordination and commonality. The LSI responsibilities are applied vertically across the SoS to ensure integration and interoperability for each mission capability area. The Stakeholder Architecture is essential for supporting LSI processes and communication methods to best influence the enterprise trade space.

A cornerstone of an effective SoS is governance. Governance is the structure and relationships among key stakeholders that determine and organization's direction and performance (Hicks, 2008). Governance provides the set of decision-making criteria, policies, processes, and actions that guide the stakeholder architecture to achieve the enterprise goals and objectives (Vaneman & Jaskot, 2013).

The LSI governance challenge is to transition from a program focus, where governance is within the program office, to a mission capability, or SoS, focus, where the governance must occur at the SoS level, where agreements towards achieving a common objective can be agreed to among the various stakeholders, and process for conflict resolution can be defined.

Universal Enabling Resources

Universal enabling resources are those resources that support LSI-unique execution at any of the touchpoints to assert and execute the trade space. The four enabling resources and interrelated enablers apply at all levels in the LSI Enterprise Framework and are outside the responsibilities of the typical program offices. However, the LSI must be aware of these activities and navigate within them. The four enabling resources are shown in Figure 3 (NPS-NAVAIR LSI Cohort #2, 2015).

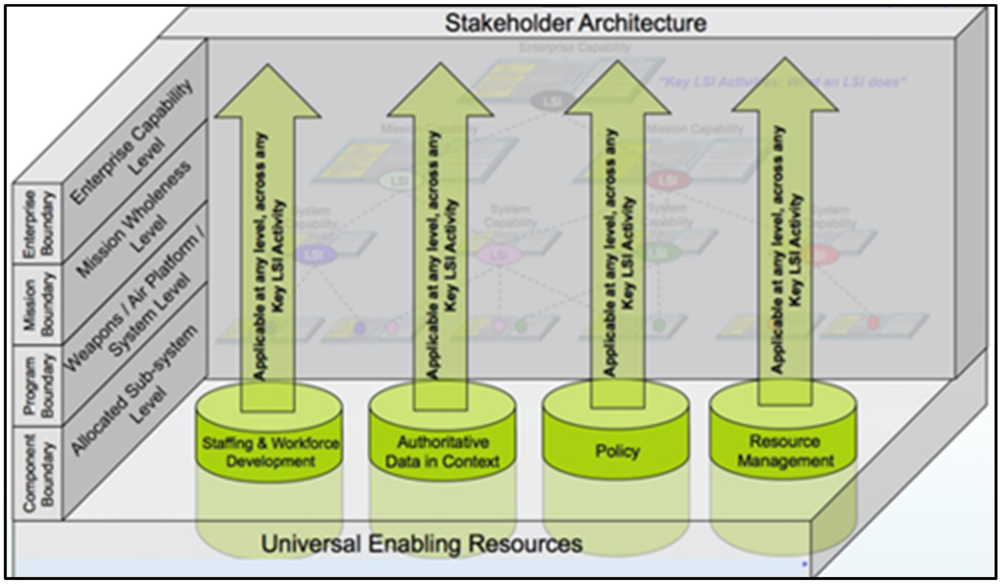

Figure 3. Universal Enabling Resources

Staffing and Workforce Development

Given that Public Law 110-181 specifies that LSI is an inherently governmental function, the key challenge for staffing and workforce development is to recruit and train qualified government engineers to rebalance roles and responsibilities traditionally performed by prime contractors. The government LSI candidates should have a "global" systems perspective and have knowledge across program boundaries. Due to the unique nature of operating in a complex SoS environment, these LSI candidates require additional depth of focus and tailored enhanced knowledge, skills, and experiences beyond that required in traditional acquisition programs (NPS-NAVAIR LSI Cohort #2, 2015; Vaneman & Carlson, 2017).

Authoritative Data in Context

The complex nature of the SoS environment makes asserting and executing the trade space essential and creates the need for sound, authoritative data across systems. In any LSI effort, everyone must have the same data and have a way to validate the authenticity and accuracy of the data to be used for decisions. "Authoritative Data in Context" includes a comprehensive integrated set of programmatic, technical, and stakeholder data that enables a shared common understanding of the trade space (NPS-NAVAIR LSI Cohort #2, 2015; Vaneman & Carlson, 2017).

Policy

Policy consists of the technical, organizational, and legal guidance and constraints of the LSI organization. This may include public law, civil mandates, legal rulings, competency policies, certification requirements, and other overarching guidance that must be accounted for by an LSI when executing any of the touchpoints at any level. These policies provide common guidance across the organizational levels, though the relative impact and flexibility of these policies may vary (NPS-NAVAIR LSI Cohort #2, 2015; Vaneman & Carlson, 2017).

Resource Management

Resource management includes a cost, schedule, and performance resource triad that captures the relationship between the financial, timing, and capability aspects of the total system. When considered against a set of requirements, the resource triad is necessarily constrained by limiting the available resources to a bounded set (NPS-NAVAIR LSI Cohort #2, 2015; Vaneman & Carlson, 2017).

The LSI Enterprise Framework Assembled

Figure 4 (NPS-NAVAIR LSI Cohort #2, 2015) depicts the LSI Enterprise Framework assembled from the four layers, the LSI Touchpoints, stakeholder architecture and governance, and the universal enabling resources. This framework allows for the alignment of key LSI activities across the enterprise to be aligning the appropriate touchpoint to the various LSI levels and tasks. The framework identifies the internal and external organizational dependencies through the stakeholder architecture. Through the universal enabling resource, staffing, and workforce development, policies, resource management, and the authoritative data context can be applied as required throughout the enterprise. Finally, governance empowers decisions across the enterprise by providing a set of decision-making criteria, policies, processes, and actions that guide the stakeholder architecture to achieve the enterprise goals and objectives.

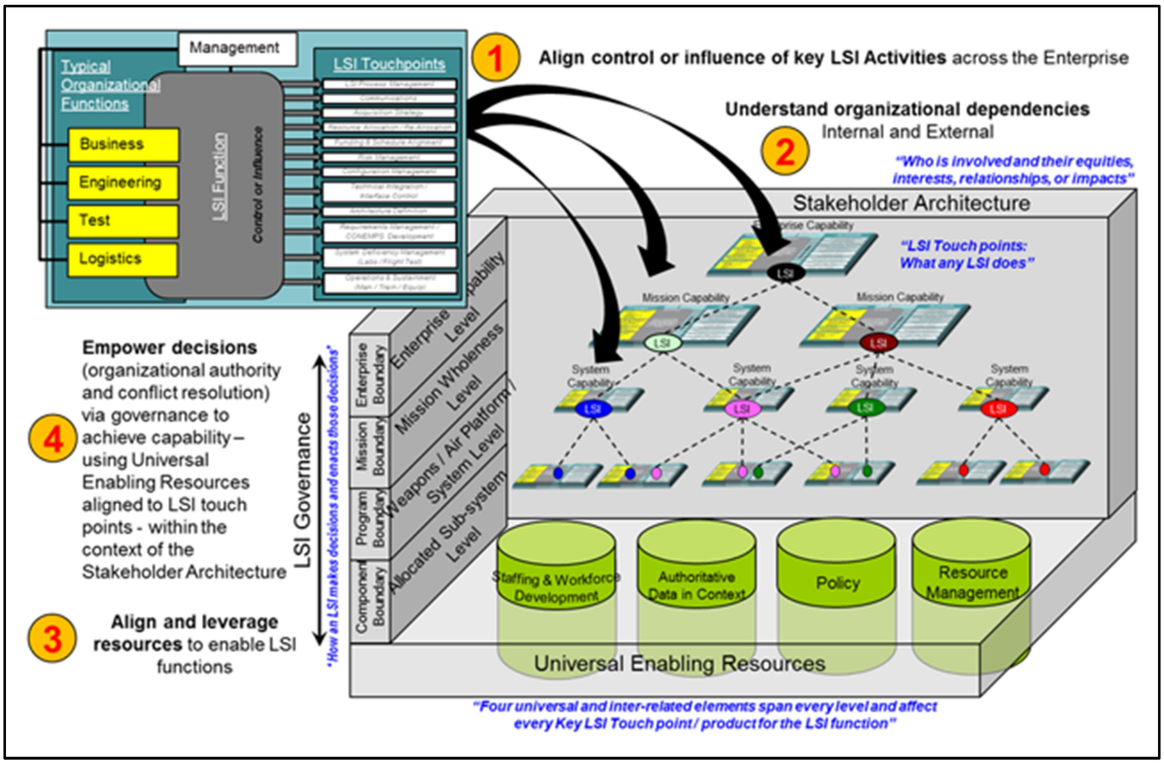

Figure 4. The LSI Enterprise Framework

Ongoing Research

The U.S. Navy has been exploring and developing strategies and approaches to address the engineering and acquisition challenges associated with SoS and complex systems. LSI is the broadest strategy encompassing the widest swath across the SoS life cycle. However, LSI is not the only strategy to address SoSE&I activities. Other strategies to date include Integration and Interoperability (I&I) and Information Technology Technical Authority (IT TA). While each strategy offers insights and partial solutions to the challenges posed by this complex systems development and acquisition environment, none address the complete problem to the depth required.

Our current research is exploring the strengths of each of these concepts and provides a framework that will better define LSI across the SoS life cycle. The following are the research questions, and the proposed methodology:

QUESTION 1: What is the correlation between the System of System Engineering and Integration, Integration and Interoperability, and Lead System Integrator concepts?

METHODOLOGY 1: Develop a model that correlates the concepts of SOSE&I, I&I, and LSI. The model will include inputs and outputs of each phase within the SoS life cycle. The model will be generated by a review of existing documentation and collaboration with the SYSCOMS. This model will serve as the baseline for further research tasks and can be tailored to individual organizations.

QUESTION 2: How can correlating SOSE&I and I&I with LSI improve the engineering management of SoS and complex systems, and facilitate acquisition strategies that improve the belonging, connectivity, and integration of SoS and complex systems to better satisfy mission objectives?

METHODOLOGY 2: Using case studies, derived from SYSCOM interactions, examine how the model will improve the engineering and acquisition of SoS and complex systems. Revise the model as necessary. This analysis will allow the research team to test the generic model against specific cases.

QUESTION 3: How does the correlated LSI model apply across non-Navy development and acquisition, and within the Department of Defense?

M**ETHODOLOGY 3**: Apply the LSI model and lessons learned to at least one non-Navy organization within the DoD. Revise and tailor the model as necessary. This analysis will allow the research team to demonstrate that the model is extensible within the DoD.

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