

Fundamental Characteristics of SoS SE

Purpose: This paper provides baseline characteristics of systems engineering (SE) for systems of systems (SoS) in the DoD, reflecting NDIA SoS SE Committee considerations. The paper is intended to support exchanges around the work of this committee, particularly the chairmen of other committees of the NDIA SE Division, in discussion of shared issues on SoS and SoS SE.

Defining SoS and Types of SoS: An SoS is defined as “a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities”. There are four types of SoS:

- **Virtual** Virtual SoS lack a central management authority and a centrally agreed upon purpose for the system-of-systems. Large-scale behavior emerges—and may be desirable—but this type of SoS must rely upon relatively invisible mechanisms to maintain it.
- **Collaborative** In collaborative SoS the component systems interact more or less voluntarily to fulfill agreed upon central purposes.
- **Acknowledged** Acknowledged SoS have recognized objectives, a designated manager, and resources for the SoS; however, the constituent systems retain their independent ownership, objectives, funding, and development and sustainment approaches. Changes in the systems are based on collaboration between the SoS and the system. Acknowledged SoS are the primary form of DoD SoS and are the focus of this paper.
- **Directed** Directed SoS are those in which the integrated system-of-systems is built and managed to fulfill specific purposes. It is centrally managed during long-term operation to continue to fulfill those purposes as well as any new ones the system owners might wish to address. The component systems maintain an ability to operate independently, but their normal operational mode is subordinated to the central managed purpose.

Characteristics of SoS in the DoD Today: The challenges of “*acknowledged SoS*” include recognition of capability needs, management and SE of the SoS, and continued management and technical autonomy of the constituent systems. Examples of this type of SoS are the Missile Defense Agency’s Ballistic Missile Defense System (BMDS), the Air Force’s Air Operations Center and the Navy’s Naval Integrated Fires Counter Air capability. A typical strategy for providing new SoS capability is to add functionality to the constituent systems, which in most cases continue to be needed for their original requirements. Consequently, while constituent systems adopt functions to support the SoS, the ownership or management of these systems remains unchanged and they continue to evolve based on their own requirements and development processes, and independent funding. The resulting dual levels of management, objectives, and funding create system engineering and management challenges for both the SoS and the systems, especially when their objectives are not well aligned.

Applying SE to Acknowledged SoS: The SE consequences of these SoS characteristics include:

- SoS SE does not directly control the technical development of all of the systems which impact the SoS capabilities and whose stakeholders have interests beyond the SoS objectives.
- SoS SE must address SoS needs within the constraints of the individual systems to meet their own needs.
- SoS SE planning and implementation must consider and leverage the development plans of the individual systems.
- SoS SE must address the end-to-end behavior of the ensemble of systems, and the key issues which affect that behavior.

In detail beyond this summary, the DoD SoS SE Guide has identified seven core elements of SoS SE and describes how basic SE processes can be adapted to address the characteristics of SoS.