

DEPARTMENT OF DEFENSE

**Systems Engineering Guide for
Systems of Systems
*Essentials***



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This publication is intended for use by program managers and systems engineers.

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This booklet summarizes the Department of Defense (DoD) *Systems Engineering Guide for Systems of Systems*¹ by addressing the following questions:

1. What is a system of systems?
2. How is a system of systems different from a regular system?
3. How is systems engineering for a system of systems different?
4. How does the Systems Engineering Process apply?

What is a system of systems?

A system of systems (SoS) brings together a set of systems for a task that none of the systems can accomplish on its own. Each constituent system keeps its own management, goals, and resources while coordinating within the SoS and adapting to meet SoS goals. SoS can be categorized² based on their degree of centrality.

- **Virtual.** The SoS lacks central management and a centrally agreed-upon purpose.
- **Collaborative.** Component systems within the SoS interact more or less voluntarily to fulfill agreed upon-central purposes.
- **Acknowledged.** The SoS has recognized objectives, a designated manager, and resources, while the constituent systems retain their independent ownership, objectives, funding, development, and sustainment approaches.
- **Directed.** The SoS is built and managed to fulfill specific purposes. Constituent systems operate independently, but their normal operational mode is subordinate to central management purposes.

How is a system of systems different from a regular system?

- **Stakeholder Involvement.** Stakeholders exist at both system and SoS levels with competing interests and priorities.

¹ <http://www.acq.osd.mil/se/docs/SE-Guide-for-SoS.pdf>

² <http://www.acq.osd.mil/se/briefs/2008-04-08-IEEESEConf-Dahmann-Baldwin.pdf>

- **Governance.** Management and funding exist for both the SoS and individual systems. An SoS rarely has authority over all the systems.
- **Operational Focus.** SoS must meet operational objectives using systems whose objectives may not align with the SoS objectives.
- **Acquisition.** Systems align to Acquisition Category milestones and documented requirements. SoS have multiple system life cycles across acquisition programs, involving existing systems, systems under development, new developments, and technology insertion.
- **Test and Evaluation.** Testing must synchronize across multiple system life cycles and must account for the complexity of all the components working together.
- **Boundaries and Interfaces.** A system focuses on its own boundaries and interfaces. An SoS enables the flow of data, control, and functionality across the SoS while accommodating needs of the systems.
- **Performance and Behavior.** A system must perform to meet specified objectives. SoS performance must satisfy both SoS user needs and the needs of the systems.

How is systems engineering for a system of systems different?

Core Elements. Seven core elements of SoS systems engineering provide a context for applying systems engineering processes.

1. **Translate SoS capability objectives into requirements.** At the start of an SoS, its goals are often stated as needed capabilities. They must be translated into requirements on the constituent systems.
2. **Understand constituent systems and relationships.** Technical and organizational understanding of candidate systems permits selection of an optimal set of constituent systems for an SoS and facilitates downstream change. This understanding includes how a system works, how it supports SoS objectives, and its development plans.

3. **Assess SoS performance against capability objectives.** Metrics and methods for assessing SoS performance should be independent of implementation, highlighting important mission threads.
4. **Develop, evolve, and maintain an SoS architecture.** An architecture should begin with the de facto architecture of the SoS, and then address a concept of operations, functions, relationships, and dependencies of constituent systems. It includes communications, end-to-end functionality, and data flow and provides a technical framework for assessing changes. It considers the current state and plans of the systems.
5. **Monitor and assess impacts of changes on SoS performance.** Change includes changes internal to constituent systems and external demands on the SoS. Constituent systems evolve independently of the SoS. Understanding the impact of change permits intervention to forestall problems or to implement mitigation strategies.
6. **Address SoS requirements and solution options.** An SoS has requirements for the SoS and constituent systems. For the SoS, user needs must be collected, assessed, and prioritized, then options evaluated for addressing them. Options must balance needs of the systems and the SoS.
7. **Orchestrate upgrades to SoS.** Selected options must be funded, planned, contractually enabled, facilitated, integrated, and tested. Constituent systems make the changes, but SoS systems engineering orchestrates the process, coordinating, integrating, and testing across the SoS.

Crosscutting Issues. Looking across core elements and processes, five crosscutting principles apply to systems engineering for SoS.

1. **Consider organizational issues in systems engineering decisions.** Decisions about where to implement a function should be based on development schedules and funding as much as on technical issues. When a function aligns with a system's goals, funding is more likely to be available and schedules more flexible.

2. **Acknowledge roles of system-level systems engineers.** System-level systems engineers have the knowledge, responsibility, and ability to address implementation. SoS systems engineering should concentrate on risk, configuration management, and data across the SoS. An SoS Integrated Master Schedule defines key intersection points and dependencies between the SoS and systems.
3. **Conduct balanced technical management.** During early stages of an SoS, it is relatively easy to involve systems engineers of the constituent systems in all aspects of SoS systems engineering. This level of involvement is not sustainable, however; rather employ transparency and trust coupled with focused participation of experienced engineers.
4. **Use an architecture based on open systems and loose coupling.** Developing an SoS architecture based on open systems and loose coupling accommodates the changing needs of users and frees engineers to apply the best technology. It lets SoS trade studies minimize concerns about interfaces between elements and acts as a roadmap for evolving constituent systems.
5. **Focus on design strategy and trades.** SoS are typically evolutionary and deliver increments of capability over time. Design analysis, both up-front and ongoing, facilitates the evolution.

Summary: How does the Systems Engineering Process apply?

This booklet summarizes systems engineering for SoS. DoD SoS are modifications to ensembles of existing and new systems that together address needs. An SoS is an overlay on systems, wherein the systems retain their identity and, concurrently with the SoS, continue their management and engineering.

Seven core elements characterize SoS systems engineering and provide a context for applying systems engineering. In SoS, systems engineering must

1. Translate SoS capability objectives into requirements
2. Understand constituent systems and relationships

3. Assess SoS performance against capability objectives
4. Develop, evolve, and maintain an SoS architecture
5. Monitor and assess impacts of changes on SoS performance
6. Address SoS requirements and solution options
7. Orchestrate upgrades to SoS.

Finally, five crosscutting principles apply to systems engineering for SoS:

1. Consider organizational issues in systems engineering decisions.
2. Acknowledge roles of system-level systems engineers.
3. Conduct balanced technical management.
4. Use an architecture based on open systems and loose coupling.
5. Focus on design strategy and trades.

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