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Systems and software engineering — Guidelines for the utilization of ISO/IEC/IEEE 15288 in the context of system of systems (SoS)

Ingénierie des systèmes et du logiciel — Lignes directrices pour l'utilisation de l'ISO/IEC/IECC 15288 dans le contexte d'un système de systèmes (SdS)

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Contents

Page

Foreword v
Introduction vi
1 Scope 1
2 Normative References 1
3 Terms, definitions, and abbreviated terms 1
3.1 Terms and definitions 1
3.2 Abbreviated terms 3
4 Relationship to other standards 3
5 Key concepts and application 4
5.1 Differences between systems and SoS 4
5.2 Managerial and operational independence 7
6 Application of system life cycle processes to SoS 10
6.1 Agreement processes 10
6.1.1 General 10
6.1.2 Acquisition process 12
6.1.3 Supply process 13
6.2 Organizational project-enabling processes 15
6.2.1 General 15
6.2.2 Life cycle model management process 16
6.2.3 Infrastructure management process 17
6.2.4 Portfolio management process 18
6.2.5 Human resource management process 20
6.2.6 Quality management process 21
6.2.7 Knowledge management process 22
6.3 Technical management processes 23
6.3.1 General 23
6.3.2 Project planning process 24
6.3.3 Project assessment and control process 25
6.3.4 Decision management process 27
6.3.5 Risk management process 28
6.3.6 Configuration management process 29
6.3.7 Information management process 30
6.3.8 Measurement process 31
6.3.9 Quality assurance process 32
6.4 Technical processes 33
6.4.1 General 33
6.4.2 Business or mission analysis process 36
6.4.3 Stakeholder needs and requirements definition process 37
6.4.4 System requirements definition process 39
6.4.5 Architecture definition process 41
6.4.6 Design definition process 44
6.4.7 System analysis process 46
6.4.8 Implementation process 47
6.4.9 Integration process 48
6.4.10 Verification process 49
6.4.11 Transition process 51
6.4.12 Validation process 52
6.4.13 Operation process 54
6.4.14 Maintenance process 55
6.4.15 Disposal process 56
Bibliography 58

IEEE notices and abstract **59**

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the rules given in the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 7, *Systems and software engineering*, in cooperation with the Systems and Software Engineering Standards Committee of the IEEE Computer Society, under the Partner Standards Development Organization cooperation agreement between ISO and IEEE.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Application of systems engineering to systems of systems has become increasingly important for the realization and sustainability of large and persistent sociotechnical systems in domains as varied as healthcare, transportation, energy, and defense, and contexts such as corporations, cities, and government. This has been intensified in the last fifteen years by the pervasiveness of information technology (IT), illustrated by new technologies and paradigms such as Sensor Networks, Cloud Computing, the Internet of Things, Big Data, Smart Devices and Ambient Intelligence. It is, for instance, the application of these technologies to cities that transform them into smarter cities.

This document provides guidance for the utilization of ISO/IEC/IEEE 15288 in the context of SoS. While ISO/IEC/IEEE 15288 applies to systems in general (including constituent systems), this document provides guidance on the application of these processes to the special case of SoS. However, ISO/IEC/IEEE 21840 is not a self-contained SoS replacement for ISO/IEC/IEEE 15288. This document is intended to be used in conjunction with ISO/IEC/IEEE 15288, ISO/IEC/IEEE 21839 and ISO/IEC/IEEE 21841 and is not intended to be used without them.

For example, ISO/IEC/IEEE 21841 provides a taxonomy for SoS, providing specific viewpoints that align with stakeholder concerns. Using a taxonomy in conjunction with this document facilitates better communications among the various stakeholders that are involved in activities like governance, engineering, operation, and management of these SoS. However, this document does not require the use of any specific taxa in ISO/IEC/IEEE 21841.

Systems and software engineering — Guidelines for the utilization of ISO/IEC/IEEE 15288 in the context of system of systems (SoS)

1 Scope

This document provides guidance on the application of processes in ISO/IEC/IEEE 15288 to systems of systems (SoS). The scope of this document is the same as ISO/IEC/IEEE 15288, which addresses more than systems engineering activities.

NOTE 1 Throughout the document, there is mixed use of "system of systems" and "systems of systems". "SoS" could refer to a system of systems or systems of systems. Similarly, "CS" could refer to a constituent system or constituent systems.

This document provides general guidance for each ISO/IEC/IEEE 15288 process and process outcome in the context of SoS, but it does not address specific activities, tasks, methods, or procedures. Additional processes and process outcomes unique to SoS can still be needed and are not covered by this document.

This document explores the similarities and differences between systems and SoS and, by extension, the similarities and differences between engineering of systems and SoS. The guidance contained in this document is expected to evolve as the discipline matures.

NOTE 2 In many cases, this document notes that ISO/IEC/IEEE 15288 processes or process outcomes "... applies as stated to SoS." Some interpretation within the context of SoS can still be needed.

2 Normative References

There are no normative references in this document.

3 Terms, definitions, and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

NOTE For additional terms and definitions in the field of systems and software engineering, see ISO/IEC/IEEE 24765, which is published periodically as a "snapshot" of the SEVOCAB (Systems and software Engineering Vocabulary) database and which is publicly accessible at www.computer.org/sevocab.

ISO, IEC, and IEEE maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/

— IEC Electropedia: available at http://www.electropedia.org/

— IEEE Standards Dictionary Online: available at: http://dictionary.ieee.org

3.1.1
capability
measure of capacity and the ability of an entity (*system* (3.1.8), person or organization) to achieve its objectives

[SOURCE: ISO/IEC 19770-1:2017, 3.10, modified — Note 1 to entry has been removed.]

3.1.2
constituent system
independent *system* (3.1.8) that forms part of a *system of systems* (SoS) (3.1.10)

Note 1 to entry: Constituent systems can be part of one or more SoS. Each constituent system is a useful system by itself, having its own development, *management* (3.1.5), utilization, goals, and resources, but interacts within the SoS to provide the unique *capability* (3.1.1) of the SoS.

[SOURCE: ISO/IEC/IEEE 21839:2019, 3.1.1]

3.1.3
emergence
principle that entities exhibit properties which are meaningful only when attributed to the whole, not to its parts

Note 1 to entry: These properties cannot be reduced or decomposed back down to the those of any individual *constituent system* (3.1.2).

Note 2 to entry: The definition is adapted from Reference [9].

3.1.4
governance
process of establishing and enforcing strategic goals and objectives, organizational policies, and performance parameters

[SOURCE: ISO/IEC 24765:2017, 3.1757, modified — The article "the" at the beginning of the definition has been removed.]

3.1.5
management
system (3.1.8) of controls and processes required to achieve the strategic objectives set by the organization's governing body

Note 1 to entry: Management is subject to the policy guidance and monitoring set through corporate *governance* (3.1.4).

[SOURCE: ISO/IEC/IEEE 24765:2017, 3.2338]

3.1.6
satisficing
decision technique that discards any alternative with an attribute value outside an acceptable range

[SOURCE: ISO/IEC/IEEE 24765:2017, 3.3601]

3.1.7
stage
period within the life cycle of an entity that relates to the state of its description or realization

Note 1 to entry: As used in this document, stages relate to major progress and achievement milestones of the entity through its life cycle.

Note 2 to entry: Stages often overlap.

[SOURCE: ISO/IEC/IEEE 15288:2015, 4.1.43, modified — The expression "this International Standard" has been replaced with "this document".]

3.1.8
system
combination of interacting elements organized to achieve one or more stated purposes

[SOURCE: ISO/IEC/IEEE 15288:2015, 4.1.46, modified — Note 1, 2, and 3 to entry have been removed.]

3.1.9
system-of-interest
system (3.1.8) whose life cycle is under consideration

Note 1 to entry: In this document, the system-of-interest is a *system of systems* (3.1.10).

[SOURCE: ISO/IEC/IEEE 15288:2015, 4.1.48, modified — The words "in the context of this International Standard" have been removed; Note 1 to entry has been added.]

3.1.10
system of systems
set of *systems* (3.1.8) and system elements that interact to provide a unique *capability* (3.1.1) that none of the *constituent systems* (3.1.2) can accomplish on its own

Note 1 to entry: System elements can be necessary to facilitate interaction of the constituent systems in the system of systems.

[SOURCE: ISO/IEC/IEEE 21839:2019, 3.1.4, modified — The abbreviated term "SoS" has been removed.]

3.1.11
system life cycle
period that begins when a *system* (3.1.8) is conceived and ends when the system is no longer available for use

[SOURCE: ISO/IEC/IEEE 24765:2017, 3.4108]

3.1.12
taxonomy
scheme that partitions a body of knowledge and defines the relationships among the pieces

[SOURCE: ISO/IEC/IEEE 24765:2017, 3.4167, modified — Note 1 to entry has been removed.]

3.2 Abbreviated terms

CS	constituent system, constituent systems
SE	systems engineering
SOI	system of interest
SoS	system of systems, systems of systems
SoSE	system of systems engineering

4 Relationship to other standards

This document is part of a set of documents that are intended to be used together:

ISO/IEC/IEEE 15288 provides the fundamental basis for this document by establishing a model set of system life cycle processes.

ISO/IEC/IEEE 21839 addresses SoS considerations in life cycle stages of a system.

This document provides guidance on the use of ISO/IEC/IEEE 15288 in the context of SoS, including considerations for how CS relate to each other within the SoS. However, the use of any specific taxa in ISO/IEC/IEEE 21841 is not required.

ISO/IEC/IEEE 21841 provides a taxonomy for SoS, providing specific viewpoints that align with management and governance concerns. Using a taxonomy in conjunction with this document facilitates better communications among the various stakeholders that are involved in activities like governance, engineering, operation, and management of these SoS.

Figure 1 highlights these relationships.

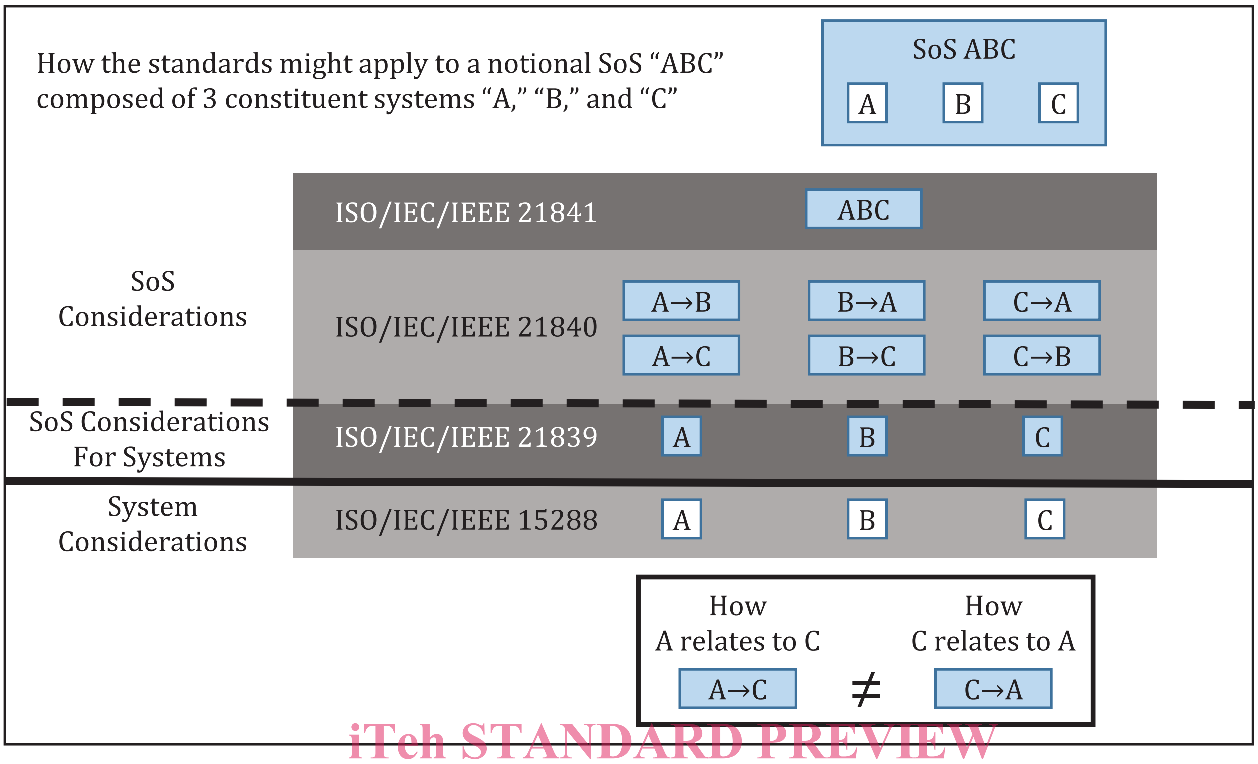


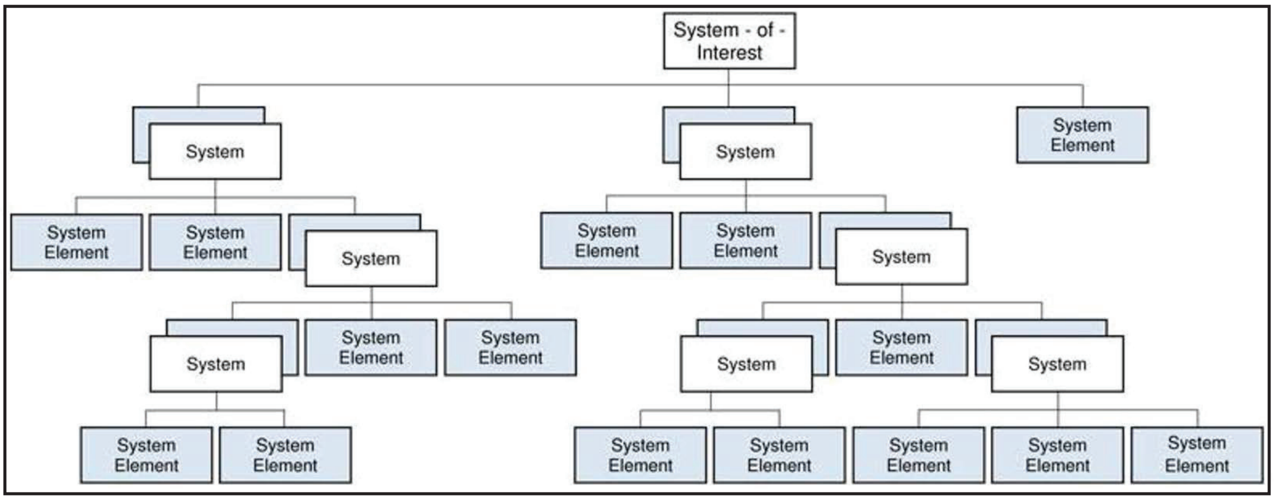
Figure 1 — Relationship between the standards

5 Key concepts and application

5.1 Differences between systems and SoS

To apply the guidance in the document, it is necessary to understand the differences between systems and SoS in which the CS are managerially and operationally independent[11]. Figure 2 shows that an SOI consists of system elements, some of which could be systems themselves. These systems also consist of system elements, some of which could be systems and so on. ISO/IEC/IEEE 15288 can be applied to any of these systems. If SoS were the same as systems, but just on a bigger scale, there would be little need for additional guidance.

It is important to note that a collection of systems may not be an SoS. For example, Figure 2 shows a collection of systems and system elements, but is this an SoS?



NOTE This figure is reproduced from ISO/IEC/IEEE 15288:2015, Figure 2.

Figure 2 — Overview of a system

It is not possible to determine from a hierarchy diagram if a collection of systems is an SoS. Rather than being described in terms of hierarchies, SoS are often described as general networks as shown in Figure 3.

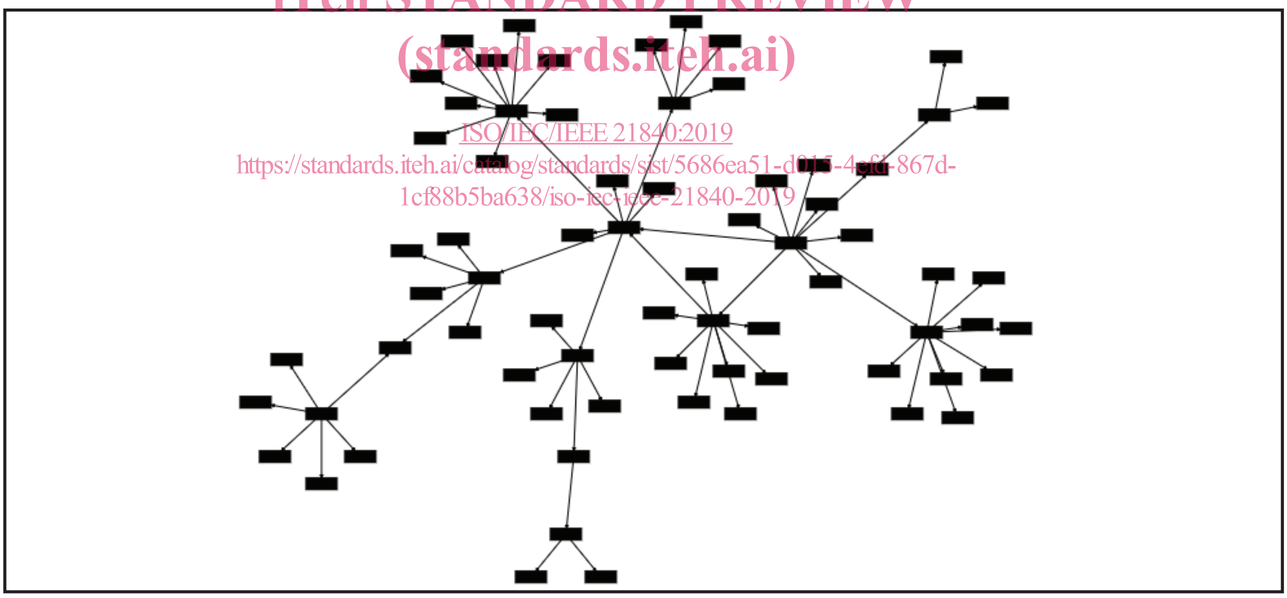


Figure 3 — Overview of an SoS

Within an SoS, each CS is an independent system that forms part of an SoS. CS can be part of one or more SoS. Each CS is a useful system by itself, having its own development, management, utilization, goals, and resources, but interacts within the SoS to provide the unique capability of the SoS. These additional attributes are what distinguish SoS from a collection of systems.

The differences between a system and an SoS are not in the physical or hierarchical structure of the component parts, but rather in the behavioral and managerial characteristics of those parts. The differences between systems and SoS (and between SE and SoSE) are complex. Table 1 describes examples of drivers of SE compared with SoSE, while Table 2 and Table 3 describe some of the differences between systems and SoS. These differences reflect the attributes or characteristics around which the guidance on the application of ISO/IEC/IEEE 15288 to SoS are framed.

However, it is important to understand that characteristics differ between system and SoS, and are not mutually exclusive.

Table 1 — Example drivers of SE and SoSE

	SE	SoSE
Focus	Single complex system	Multiple integrated complex systems
Objective	Optimization	Satisficing, sustainment
Boundaries	Static	Dynamic
Problem	Defined	Emergent
Structure	Hierarchical	Network
Goals	Unitary	Pluralistic
Timeframe	System life cycle	Continuous
Centricity	Platform	Network
Tools	Many	Few
Management framework	Established	Various

NOTE This table is adapted from Reference [10].

Table 2 — Examples of differences between systems and SoS

Systems tend to have	SoS tend to have
A clear set of stakeholders	Multiple levels of stakeholders with mixed and possibly competing interests
Clear objectives and purpose	Multiple and possibly contradictory objectives and purpose
Clear management structure and clear accountabilities	Disparate management structures with no clear accountability
Clear operational priorities, with escalation to resolve priorities	Multiple, and sometimes different, operational priorities with no clear escalation routes
A single life cycle	Multiple lifecycles with elements being implemented asynchronously
Clear ownership with the ability to move resources between elements	Multiple owners making individual resourcing decisions

NOTE This table is adapted from Reference [11].

Table 3 — Examples of differences between systems and SoS

Attribute	System	SoS
Autonomy	Autonomy is ceded by parts to grant autonomy to the system.	Autonomy is retained and exercised by CS while contributing to fulfilling the purpose of the SoS.
Belonging	Parts are akin to family members; they did not choose themselves but came from parents. Belonging of parts is in their nature.	While some CS are directed or coerced to belong to SoS, some CS could be unaware of the SoS. Some CS choose to belong on a cost/benefits basis; also, to cause greater fulfillment of their own purposes, and because of belief in the overarching SoS purpose.
Connectivity	Prescient design, along with parts, with high connectivity hidden in elements, and minimum connectivity among major subsystems.	Dynamically supplied by CS with every possibility of myriad connections between CS, possibly via a net-centric architecture, to enhance SoS capability.

NOTE This table is adapted from Reference [8].

Table 3 *(continued)*

Attribute	System	SoS
Diversity	Managed i.e. reduced or minimized by modular hierarchy; parts' diversity encapsulated to create a known discrete module whose nature is to project simplicity into the next level of the hierarchy.	Increased diversity in SoS capability achieved by released autonomy, committed belonging, and open connectivity.
Emergence	Foreseen, both good and bad behavior, and designed in or tested out as appropriate.	Enhanced by deliberately not being foreseen, though its crucial importance is, and by creating an emergence capability climate, that will support early detection and elimination of bad behaviors.

NOTE This table is adapted from Reference [8].

5.2 Managerial and operational independence

ISO/IEC/IEEE 15288:2015, Annex G contains general information on SoS. Details of SoS characteristics and types in ISO/IEC/IEEE 15288:2015, G.2 are shown in the box.

> SoS are characterized by managerial and operational independence of the constituent systems, which in many cases were developed and continue to support originally identified users concurrently with users of the SoS. In other contexts, each constituent system itself is a SOI; its existence often predates the SoS, while its characteristics were originally engineered to meet the needs of their initial users. As constituents of the SoS, their consideration is expanded to encompass the larger needs of the SoS. This implies added complexity, particularly when the systems continue to evolve independently of the SoS. The constituent systems also typically retain their original stakeholders and governance mechanisms, which limits alternatives to address the needs of the SoS.
>
> Emergence is a key characteristic of SoS – the unanticipated effects at the systems of systems level attributed to the complex interaction dynamics of the constituent systems. In SoS, constituent systems are intentionally considered in their combination, so as to obtain and analyze outcomes not possible to obtain with the systems alone. The complexity of the constituent systems and the fact they may have been designed without regard to their role in the SoS, can result in new, unexpected behaviors. Identifying and addressing unanticipated emergent results is a particular challenge in engineering SoS.

Applying SE to SoS aims to engineer the desired emergent behavior and minimize the undesired emergent behavior - the anticipated effects are generally the reason for the SoS conceptualization.

Systems operate within a context of managerial control which is subject to governance[7]. Organizations govern a portfolio of programs through goals and objectives, subject to laws, regulations, and external agreements such as contracts. Programs manage some number of projects to achieve those goals and objectives.

An SoS comprises CS and other system elements that can be necessary to facilitate interaction of the CS in the SoS. Relationships between CS and system elements affect the SoS. Systems that do not interact are not part of an SoS as shown in Figure 4. Organization A owns System V which consumes inputs and produces outputs. Likewise, Organization B owns System W which also consumes inputs and produces outputs. Systems have capabilities. Outcomes can be partially or totally achieved when the system behaves. Because Systems V and W do not interact, there is no SoS.

NOTE The terms "organization" and "owns" suggest that individual CS could reside in different companies or enterprises. However, CS could reside within different organizational elements within a particular company or enterprise.

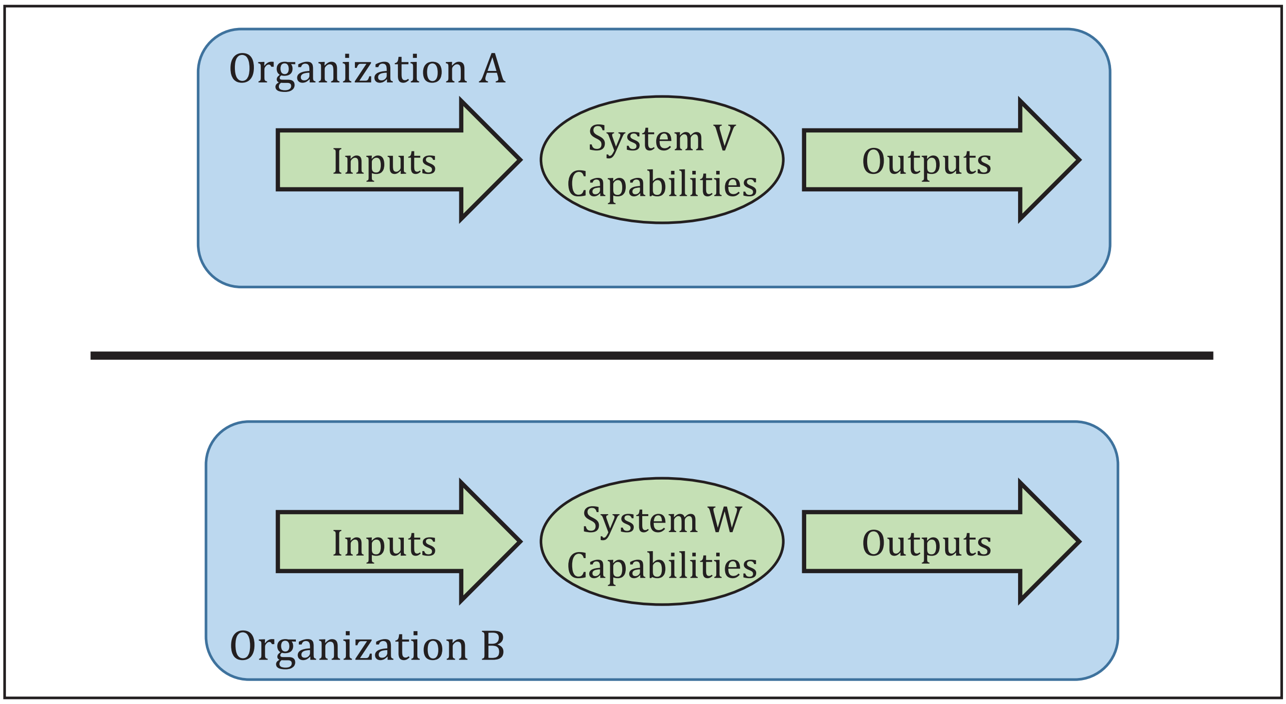


Figure 4 — Systems that don't interact are not part of an SoS

An essential characteristic is that CS within the SoS are operationally independent[11]. That is, the CS can (and do) operate independently to fulfil some number of purposes on their own, separate from the SoS. However, an SoS is a set of systems and system elements that interact to provide a unique capability that none of the CS can accomplish on its own as shown in Figure 5. Because the SoS provides unique capabilities beyond those of the CS, the SoS could have unique inputs beyond inputs originally needed by the CS. Also, while it is possible that the emergent capability is provided by one of the CS, this isn't necessarily the case. Some SoS can (and do) provide outputs not conveyed by one of the CS.

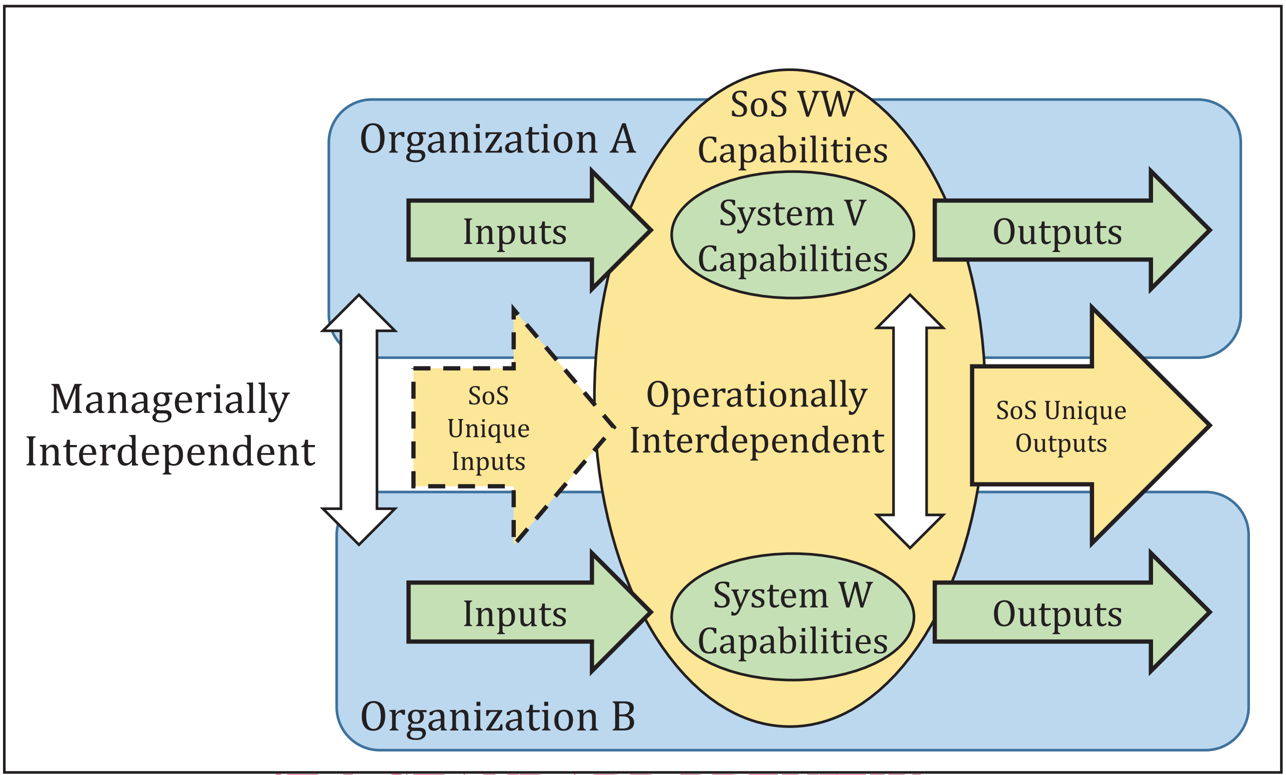


Figure 5 — A set of systems and system elements that interact to provide a unique capability

SoS add value through the unique SoS capabilities from the integration and/or sequencing capabilities of CS and other elements in time and space. Consequently, SoS accommodate delivery of outputs to multiple consumers that could have different priorities and expectations. While CS operate independently from each other for their own purposes, they also operate interdependently with each other and other elements to produce the SoS outputs. CS are never totally independent, yet they are also never totally subservient to the SoS[8]. Unlike a system, which has been designed to fulfil a purpose and an expected quality of service, the quality of service provided by an SoS can be subject to variation.

Another essential characteristic is that CS within the SoS are both managerially independent and interdependent. Managerial independence suggests that the CS are likely to be managed by organizations that retain some degree of independence even though they are interdependent while participating in SoS. The implication is that these organizations could have goals and objectives for the CS that differ from those of the SoS. If so, there is likely some degree of independence and interdependence of governance, as well as some degree of independence and interdependence of management. Regardless of the means of managing the organizations, alignment (or lack thereof) in the goals and objectives will affect the SoS. While some CS are directed or coerced to belong to SoS, some CS could be unaware of the SoS. Some CS choose to belong on a cost/benefits basis, also to cause greater fulfillment of their own purposes, and because of their belief in the overarching SoS purpose.

Figure 6 highlights the various kinds of relationships for governance and management. Multiple projects can be necessary to design, produce, and operate a system. SoS composed from some combination of systems U, V, and W would need to address the operational independence of the systems and the managerial independence of organizations.