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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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Foreword

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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.

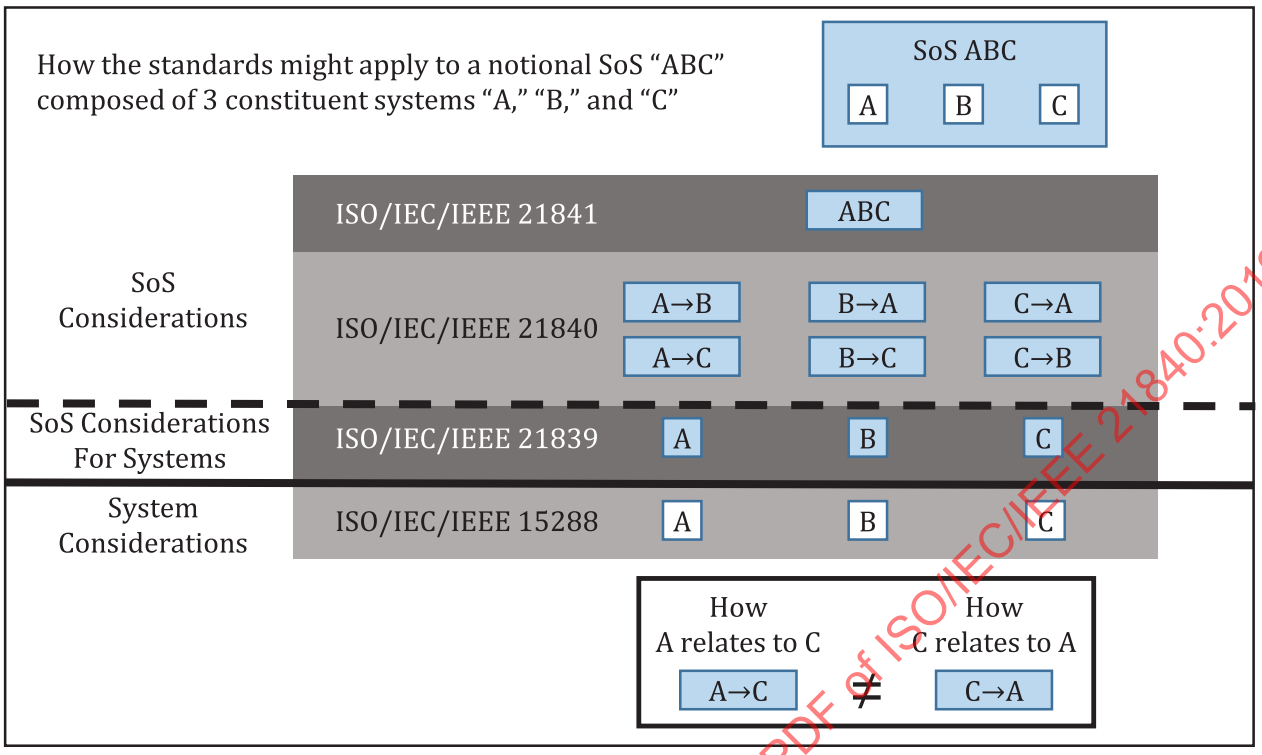


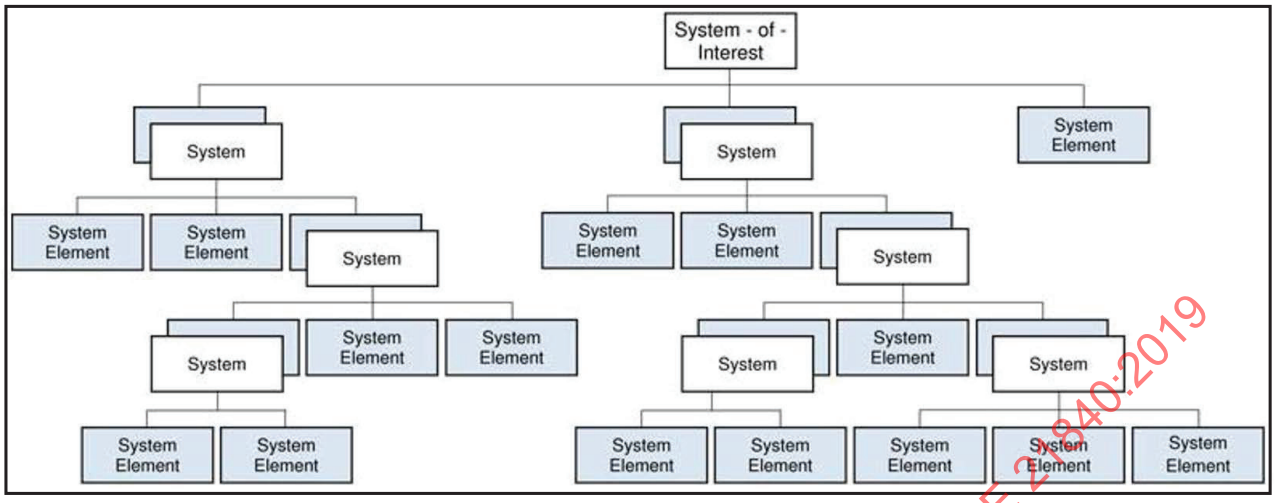
Figure 1 — Relationship between the standards

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.

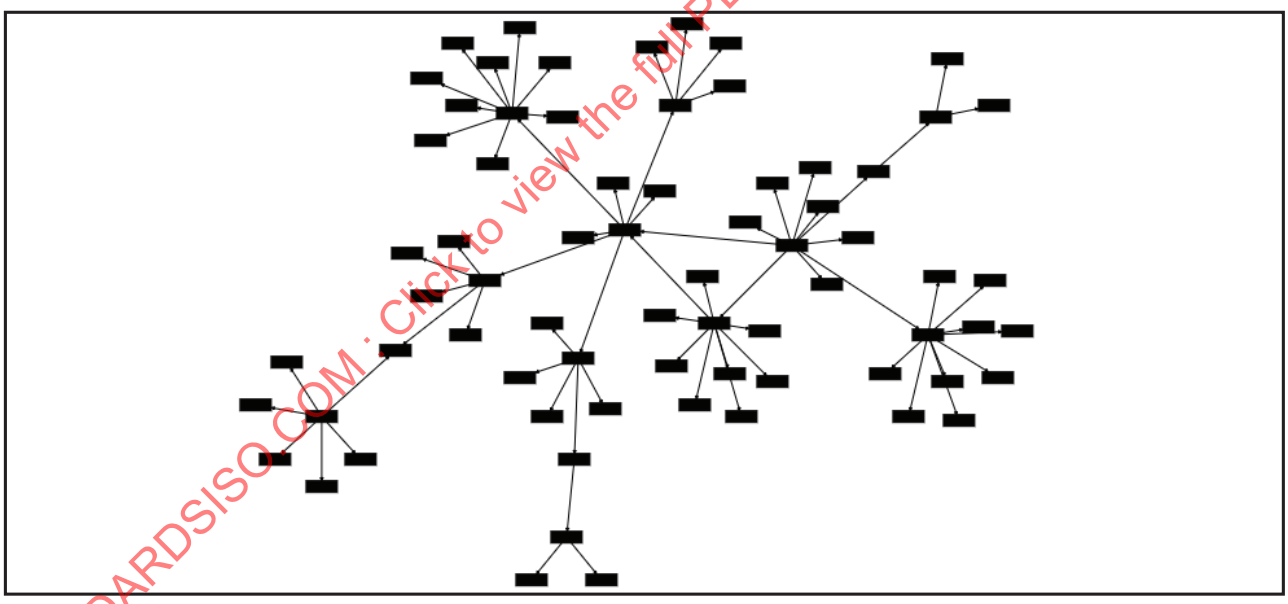


Figure 3 — Overview of an SoS

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.

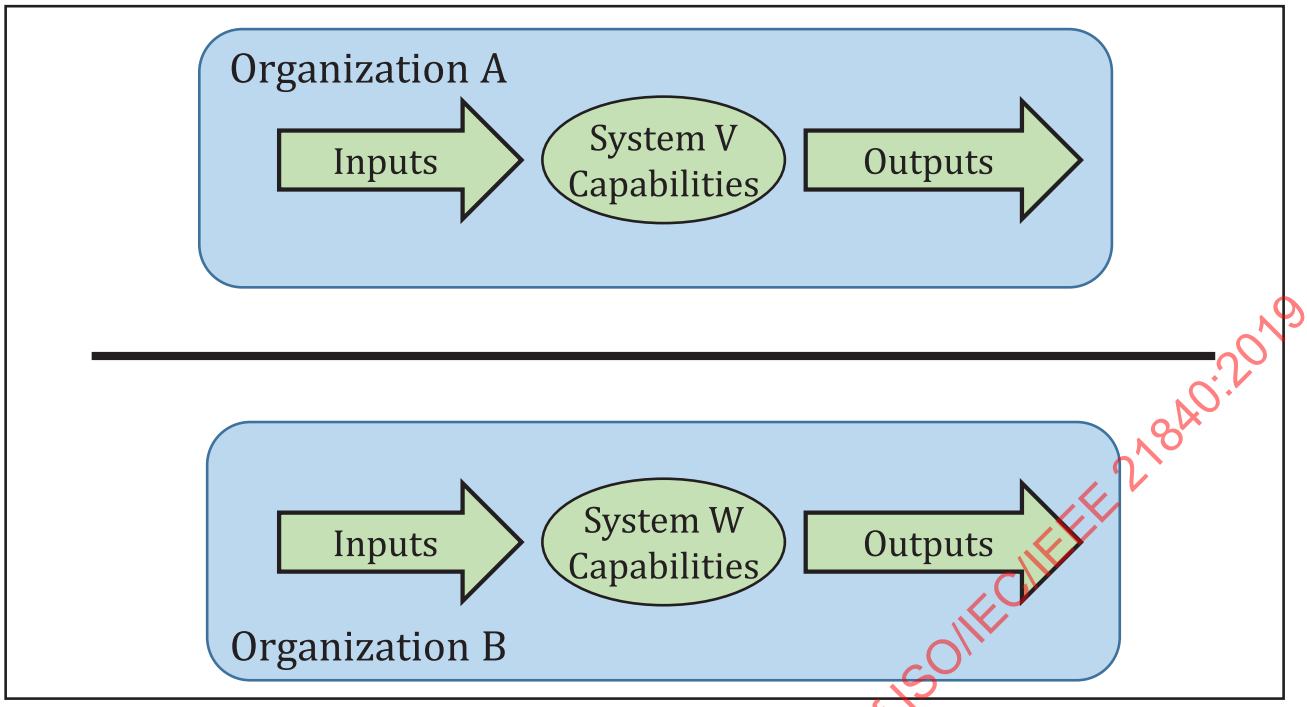


Figure 4 — Systems that don't interact are not part of an SoS

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.

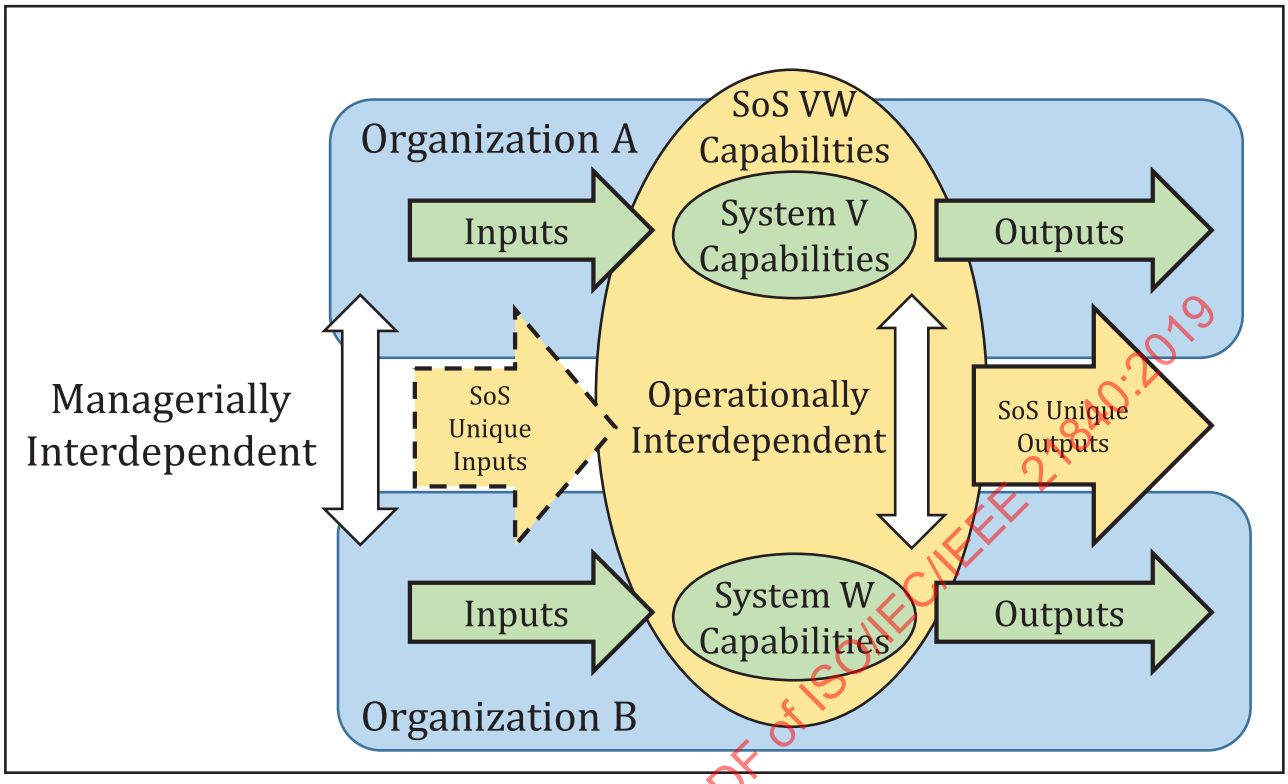


Figure 5 — A set of systems and system elements that interact to provide a unique capability

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.

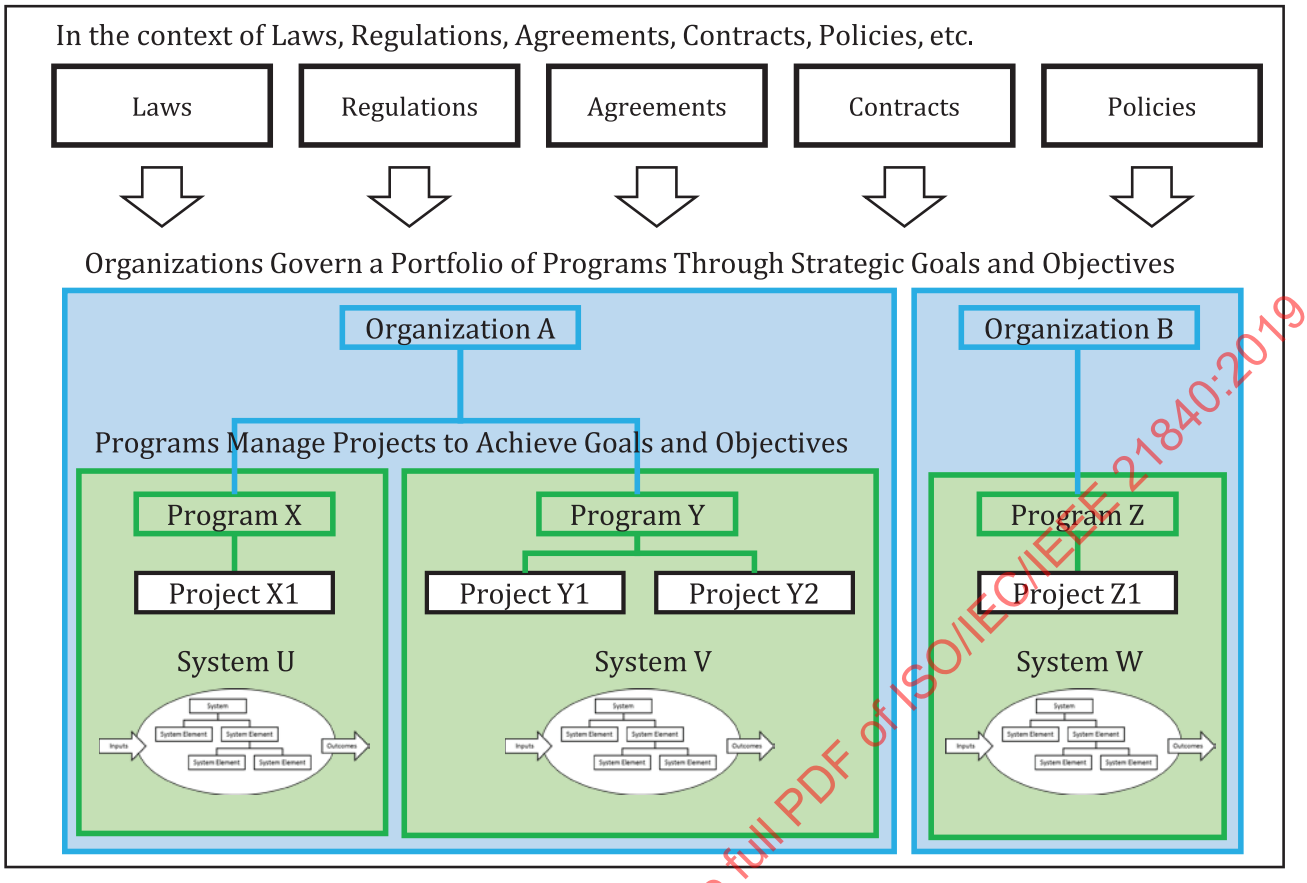


Figure 6 — Degree of operational and managerial independence varies

The processes from ISO/IEC/IEEE 15288 are applied in a highly iterative and concurrent manner. In some cases, there could be "waves" of SoS revision. In other cases, SoS changes could occur continually, with many processes operating on a continuous basis to implement evolutionary change. These complexities do not invalidate ISO/IEC/IEEE 15288 or SE, but rather form an alternative context for their application. The descriptions of the use of the ISO/IEC/IEEE 15288 processes and outcomes should be reconsidered in light of the alternative context. Clause 6 provides general guidance in the context of SoS.

6 Application of system life cycle processes to SoS

6.1 Agreement processes

6.1.1 General

ISO/IEC/IEEE 15288:2015, 6.1 contains general information on the application of system life cycle agreement processes to a system as shown in the box.

This subclause specifies the requirements for the establishment of agreements with organizational entities external and internal to the organization.

The Agreement Processes consist of the following:

a) Acquisition process – used by organizations for acquiring products or services;

b) Supply process – used by organizations for supplying products or services.

These processes define the activities necessary to establish an agreement between two organizations. If the Acquisition process is invoked, it provides the means for conducting business with a supplier. This may include products that are supplied for use as an operational system, services in support of operational activities, or elements of a system being provided by a supplier. If the Supply process is invoked, it provides the means for an agreement in which the result is a product or service that is provided to the acquirer.

NOTE Security is an increasing concern in systems engineering. See ISO/IEC 27036, *Security techniques — Information security for supplier relationships*, for requirements and guidance for suppliers and acquirers on how to secure information in supplier relationships. Specific aspects of information security supplier relationships are addressed in Parts 3 and Part 4.

ISO/IEC/IEEE 15288:2015, Annex G contains general information on the application of system life cycle processes to SoS. Details of agreement processes in ISO/IEC/IEEE 15288:2015, G.3.2 are shown in the box.

Agreement Processes are crucial for SoS because they establish the modes of developmental and operational control among the organizations responsible for the SoS and the often independent constituent systems. Constituent systems, which are acquired and managed by different organizations, often hold original objectives that may not align with those of the SoS. Except in the directed SoS case, the SoS organization cannot task a constituent system organization without their cooperation. In an acknowledged or collaborative SoS, these tasks are balanced against the tasks of the constituent system as a SOI in its own right. For virtual SoS, agreement processes may be informal, or considered only for analysis purposes.

The Agreement processes description from ISO/IEC/IEEE 15288 applies as stated to SoS with the following additions.

Because CS exist already and are being used for other purposes, agreements between the CS and its suppliers can already exist. Those agreements could be particularly important if the SoS expects the CS to change to meet SoS needs. For example, if the SoS has the requirement for changes to CS, this could affect existing agreements the CS has in place with its suppliers. However, depending on the degree of operational or managerial independence, CS may not be obliged to acknowledge or adjust based on the SoS requirements.

For some SoS, it is possible that the Agreement processes as stated do not apply at all, with no evidence of Acquisition or Supply processes. In such cases, “agreement” can be considered in the conceptual sense only, in that participating CS owners could form agreements among each other. In some cases, participating CS owners could even be competing and conflicting with each other. In others, formal agreements could be absent.

In SoS, agreements can be needed when there are no existing authority arrangements between the SoS and the CS. Agreements within SoS could be formal agreements, memoranda of agreement, or other less formal agreements. Loose agreements could be more appropriate for non-critical elements, while tighter, more formal agreements and associated processes could be appropriate for managing areas of higher risk or greater criticality. However, CS could interact even without formal or explicit agreement.

ISO/IEC/IEEE 15288 does not contain processes addressing collaboration or competition. Collaboration and competition involve independent action among the CS owners that facilitate collaboration or create conflicting relationships among the CS owners and SoS owner (if any). These relationships result in dynamic changes to the CS that modify the objectives, goals, and capabilities of the SoS.

Realizing a new SoS capability that is not supported by the existing CS requires some recognition of the need for the new capability, and support for the need from the CS owners. Revised agreements for example, may be needed to establish and maintain interoperability between CS. These agreements could be obtained external to a typical SE span of control; however, application of SE processes can help influence reaching suitable agreements. The obtainment of SoS capabilities requires interaction between the CS within the SoS. These interactions could require agreements to establish and maintain interoperability among these systems. Used in concert with Interface Management, the Agreement process can be used to establish and maintain technical interface agreements between CS owners and maintainers.

6.1.2 Acquisition process

6.1.2.1 Purpose

The purpose of the Acquisition process in ISO/IEC/IEEE 15288:2015, 6.1.1 is shown in the box.

> The purpose of the Acquisition process is to obtain a product or service in accordance with the acquirer's requirements.
>
> NOTE As part of this process, the agreement is modified when a change request is agreed to by both the acquirer and supplier.

The purpose of the Acquisition process in ISO/IEC/IEEE 15288:2015, 6.1.1 applies as stated to SoS with the following additions.

For an SoS, the organization (single or collaborative) for the SoS is the acquirer and the suppliers could be the organizations that manage the CS. Organizations participating in the SoS would also have to coordinate any system elements required by the SoS beyond the CS. Terms such as participant or "partner" could be more applicable than acquirer and supplier.

In the context of SoS, an acquirer obtains the capabilities of CS, sometimes without explicit agreement, and without acquiring the CS that produced the capabilities. The acquirer could still need to obtain system elements (i.e., system elements that are not CS, or any system elements required by the SoS beyond the CS).

There could be the occasion where the functionality or interface behaviors for a CS require modification or an expectation for coordinated changes to the CS. In these cases, applying SE supports the acquisition process by defining the functional, performance or technical requirements allocated to each CS to support the capability to be achieved by the SoS when these CS interact.

6.1.2.2 Outcomes

The outcomes of the Acquisition process in ISO/IEC/IEEE 15288:2015, 6.1.1 apply as stated in the boxes with the following additions:

> a) A request for supply is prepared.

It is possible that a request for supply by the organization that governs the SoS does not have the same formality as could be expected within a system. Instead of a formal request for supply for specific products or services, a search for specific capabilities or a request for information about existing and planned capabilities can be made. In an SoS governance sense, a request for supply could only have or need partial influence on the component outcome. For example, there could be standards and rules for certain aspects of certain types of CS, but little interest in definition of the full acquisition scope of that item. Things such as collaborative and informal agreements and influencing by demonstrating potential mutual benefits (to both SoS governance and CS suppliers) could apply.

b) One or more suppliers are selected.

In an SoS, the selection of suppliers or participants can occur in several ways. The SoS could identify and negotiate the participation of a CS in an SoS. If the CS are managerially dependent, the selection of suppliers could follow a path like that of conventional systems. If the CS are managerially independent, the CS likely would decide for themselves. Rather than selecting suppliers, suppliers/candidate organizations could choose to participate in the SoS (i.e., self-select), but at least in some cases, they could be able to do so only if they play by the rules (established through the governance of the SoS) which could have some controls (e.g., shall be accredited/meet criteria to be allowed to join the SoS context) or be uncontrolled (anyone can join, but the integrated behavior is uncertain or poor unless certain rules/minimum requirements are met).

c) An agreement is established between the acquirer and supplier.

In addition to formal approaches like contracts, less formal approaches such as memoranda of agreement and memoranda of understanding can be effective in the management arrangements for some types of SoS. For some types of SoS, though, agreements could be informal or tacit. Accepting terms of use for a product or service is one type of agreement. Some types of SoS operate effectively even in the absence of agreements.

A supplier can be a freely-available source of information, or an agreement could be already held (for example, where the information is being used in a different context). In either case, it is possible that a formal agreement does not need to be established.

d) A product or service complying with the agreement is accepted.

In the context of SoS, especially if the agreement approach is informal, "compliance" could mean something different than in the context of systems, where agreements and means to compel compliance can be formal. Within an SoS, especially in the absence of a formal agreement, acquirers could find that they have little leverage over suppliers to deliver acceptable products and services on the anticipated schedule. Consequently, acquirers should adjust their plans and processes to accommodate these realities. Obtaining or using an existing CS to gain a product or service, and agreeing to its terms of use, is one type of acceptance.

Based on marketplace and trust, a CS could be trusted by an SoS customer to comply with appropriate standards without explicit evidence of that compliance (e.g., a mobile phone). If the customer subsequently finds that the CS fails in a way that shows the SoS customer that the CS is not compliant and has breached that trust, the SoS customer could remove the CS from the SoS or seek additional means to gain the appropriate trust. This kind of approach could work in non-critical environments; more critical environments with significant consequences (risk) could demand more explicit up-front compliance.

e) Acquirer obligations defined in the agreement are satisfied.

Within an SoS, acquirers can obtain capabilities from CS without explicit agreements, so an SoS acquirer could have no explicit obligations to the CS. Or, depending on the type of SoS, acquirers could have fewer or different obligations than with systems. However, if those obligations are documented in an agreement of some type, including general terms of use, the acquirer should endeavor to satisfy them.

6.1.3 Supply process

6.1.3.1 Purpose

The purpose of the Supply process in ISO/IEC/IEEE 15288:2015, 6.1.2 is shown in the box.

The purpose of the Supply process is to provide an acquirer with a product or service that meets agreed requirements.

NOTE As part of this process, the agreement is modified when a change request is agreed to by both the acquirer and supplier.

The purpose of the Supply process in ISO/IEC/IEEE 15288:2015, 6.1.2 applies as stated to SoS with the following additions.

In an SoS comprised of existing CS, those systems already have an existing acquirer for their product or service. Some CS could be willing to expand or reallocate resources to address the needs of an SoS acquirer, or agree to not change CS characteristics without notice, but some would not.

In some types of SoS, agreements could be informal or even absent.

Supply of a product or service does not necessarily mean relinquishing ownership of the product or underlying service system.

For SoS, terms such as "participant" or "partner" could be more applicable than acquirer and supplier.

6.1.3.2 Outcomes

The outcomes of the Supply process in ISO/IEC/IEEE 15288:2015, 6.1.2 apply as stated in the boxes with the following additions:

a) An acquirer for a product or service is identified.

In an SoS, identification of specific acquirers is not always necessary. For example, suppliers of some types of software are not able to identify individual acquirers. However, identifying classes of acquirers could be beneficial. Suppliers should consider which SoS (one or more) they support.

b) A response to the acquirer's request is produced.

SoS acquirers can struggle with identifying potential suppliers and requesting information from them. Requests can be informal and relatively unstructured. For example, when users of cell phones acquire an app for some purpose, it would be very difficult for them to identify and generate requests to potential suppliers individually. To mitigate this difficulty, suppliers of apps use alternative means to make the capabilities of their apps known to prospective acquirers. Effective SoS suppliers could accommodate these challenges by developing more open lines of communication with potential SoS acquirers.

SoS acquirers could set roadmaps or broad strategies that CS suppliers could implement at times that suit them. Such roadmaps could also be drivers for a coordinated change across multiple organizations (e.g., telecommunication 4G/5G standards). Proxies, such as consortia and user groups, can be used to aggregate and manage requests.

c) An agreement is established between the acquirer and supplier.

Agreements within SoS span a wide spectrum of formality, from contracts at one end of the spectrum, moving through less formal approaches such as memoranda of agreement, to memoranda of understanding to no agreements at all. For example, many types of software are licensed, not purchased. Software license agreements often include the right to use the software subject to terms and conditions. Using the software can constitute an agreement to those terms and conditions.

A supplier could be unaware that an SoS is making use of the supplier's CS capabilities. Sensitive system design and other technical information could be of value to a competitor or an adversary. The extent to which protection can be implemented and enforced should be considered.

Agreements can be less formal but can include responses to SoS roadmaps, identified standards and conformance arrangements that allow CS to participate.

d) A product or service is provided.

While the SoS provides products or services (or capabilities), the CS provide products or services (or capabilities) to the SoS and to other acquirers beyond the SoS. The CS are operationally and managerially independent as well as interdependent.

e) Supplier obligations defined in the agreement are satisfied.

For many SoS, the term "obligation" could be too strong or not applicable. For example, in some SoS where an explicit agreement does not exist, the supplier has no direct obligations. However, suppliers generally want their products and services to be used, so they have some motivation to help acquirers find usefulness in them.

These obligations could include evidence of interoperability (e.g., third party testing) or conformance as a precondition to participate in one or more SoS, but with no obligations relating to full functionality of the SoS.

f) Responsibility for the acquired product or service, as directed by the agreement, is transferred.

Due to the wide variety of agreement types and relationships between suppliers and acquirers in an SoS, care should be taken to understand the retention and allocation of ownership, responsibilities, risks, and liabilities. From the perspective of the supplier, agreements could be informal or unnecessary, or the supplier could be unaware that an SoS is making use of the supplier's CS capabilities. Consequently, transfer of ownership would not occur. For example, it is possible that some obligations regarding usage, data, and privacy transfer, while some do not.

6.2 Organizational project-enabling processes

6.2.1 General

ISO/IEC/IEEE 15288:2015, 6.2 contains general information on the application of system life cycle organizational project-enabling processes to a system as shown in the box.

The Organizational Project-Enabling Processes help ensure the organization's capability to acquire and supply products or services through the initiation, support and control of projects. These processes provide resources and infrastructure necessary to support projects and help ensure the satisfaction of organizational objectives and established agreements. They are not intended to be a comprehensive set of business processes that enable strategic management of the organization's business.

The Organizational Project-Enabling Processes consist of the following:

a) Life Cycle Model Management process;

b) Infrastructure Management process;

c) Portfolio Management process;

d) Human Resource Management process;

e) Quality Management process;

f) Knowledge Management process.

ISO/IEC/IEEE 15288:2015, Annex G contains general information on the application of system life cycle processes to an SoS. Details of Organizational project-enabling processes in ISO/IEC/IEEE 15288:2015, G.3.3 are shown in the box.

> In a typical system-of-interest, Organizational Project-Enabling Processes establish the environment in which projects are conducted. The organization establishes the processes and life cycle models to be used by projects; establishes, redirects, or cancels projects; provides resources required, including human and financial; and sets and monitors the quality measures for systems and other deliverables that are developed by projects for internal and external customers. (Subclause 6.2).
>
> In an SoS, the owners of the constituent systems usually retain responsibility for engineering their systems and they each have their own Organizational Project-Enabling Processes. Depending on the SoS type, the SoS also applies these Organizational Project-Enabling Processes to the particular considerations of the SoS - planning, analyzing, organizing, and integrating the capabilities of a mix of existing and new systems into a SoS capability.
>
> Consequently, in SoS these Organizational Project-Enabling Processes are implemented at two levels. The organizations responsible for the constituent systems implement these processes for their SOI independent of the SoS. The SoS organization (or in collaborative systems of systems by agreement of the SoS) implement these processes for the SoS for those considerations that apply to the overall SoS. For example, Human Resource Management is addressed by each constituent system organization for the engineering of their system. The SoS organization would only address this for the systems engineering activities that apply across the constituent systems to the SoS.
>
> A particular challenge in SoS engineering is the lack of alignment among the constituent system Organizational Project-Enabling Processes and those of the SoS. Constituent systems processes are designed to meet their own outcomes and may not align with those of the SoS. For example, Portfolio Management will be a constituent system responsibility in cases where the constituent system organization has full control over the constituent system and other systems and projects in its portfolio, and the SoS organization will need an approach to Portfolio Management that recognizes this.

The Organizational project-enabling processes description from ISO/IEC/IEEE 15288 applies as stated to SoS with the following addition.

To mitigate risks associated with misalignment among the CS, working groups and information sharing strategies such as roadmaps can be productive.

6.2.2 Life cycle model management process

6.2.2.1 Purpose

The purpose of the Life cycle model management process in ISO/IEC/IEEE 15288:2015, 6.2.1 is shown in the box.

> The purpose of the Life Cycle Model Management process is to define, maintain, and assure availability of policies, life cycle processes, life cycle models, and procedures for use by the organization with respect to the scope of this International Standard.
>
> This process provides life cycle policies, processes, models, and procedures that are consistent with the organization's objectives, that are defined, adapted, improved and maintained to support individual project needs within the context of the organization, and that are capable of being applied using effective, proven methods and tools.

The purpose of the Life cycle model management process in ISO/IEC/IEEE 15288:2015, 6.2.1 applies as stated to SoS with the following additions.

CS could have their own life cycle models and could be at different places within those models. The life cycle model of an SoS could be different from those of the CS. SoS can have a range of CS that may contribute to achieve the outcome such that there can be new ones in development and old ones retiring while the SoS is operating. Effective use of this process provides a context for CS joining and leaving the SoS and associated costs or financial constraints.

6.2.2.2 Outcomes

The outcomes of the Life cycle model management process in ISO/IEC/IEEE 15288:2015, 6.2.1 apply as stated in the boxes with the following additions:

a) Organizational policies and procedures for the management and deployment of life cycle models and processes are established.

The SoS and CS could have their own organizational policies and procedures, and different life cycle models for their respective systems. Depending on the degree of managerial independence, organizations governing CS could have little insight or interest in the policies, procedures, and life cycle models of the SoS or another CS.

b) Responsibility, accountability, and authority within life cycle policies, processes, models, and procedures are defined.

For each SoS, responsibility, accountability, and authority arrangements with CS should be defined and understood. Because the organizations responsible for CS manage their own systems, SoS efforts should work with these organizations and systems to establish responsibility, accountability, and authority over aspects of the SoS key to SoS objectives. It is possible that an SoS organization has responsibility for (life cycle) models, without any authority to enforce the use of those models across the CS, but they could encourage their use. Other permutations (e.g., an organization could be responsible and accountable, but not have authority) are also possible. In some SoS, no organization is responsible, accountable or has authority. Organizations responsible for CS participating in SoS should review and update their life cycle policies, processes, models, and procedures to support effective participation in an SoS.

c) Life cycle models and processes for use by the organization are assessed.

Assessment of SoS life cycle models and processes for use by the organization should consider that SoS concerns, life cycle models, and processes could differ from those of the CS. The life cycle model and process of the SoS should recognize and accommodate the life cycle model and processes of the CS. For example, in some cases, it could be possible to adapt the CS life cycle models and processes to meet the needs of the SoS. In other cases, some CS could be unable or unwilling to make such adaptations. Adaptation to SoS concerns could include alignment with SoS roadmaps or broad strategies. Reassessments could need to be made periodically.

d) Prioritized process, model, and procedure improvements are implemented.

SoS process, model, and procedure improvements should recognize that improvements needed to support the SoS are different from those needed to support the CS on its own and that the priorities of the SoS could differ from the priorities of the CS.

6.2.3 Infrastructure management process

6.2.3.1 Purpose

The purpose of the ISO/IEC/IEEE 15288 Clause 6.2.2 'Infrastructure management process' is shown in the box.

> The purpose of the Infrastructure Management process is to provide the infrastructure and services to projects to support organization and project objectives throughout the life cycle.
>
> This process defines, provides and maintains the facilities, tools, and communications and information technology assets needed for the organization's business with respect to the scope of this International Standard.

The purpose of the Infrastructure management process in ISO/IEC/IEEE 15288:2015, 6.2.2 applies as stated to SoS with the following addition.

Distinction should be made between infrastructure and services needed by organizations and their projects, which is the focus of this process, and the infrastructure and services needed by the SoS itself.

6.2.3.2 Outcomes

The outcomes of the Infrastructure management process in ISO/IEC/IEEE 15288:2015, 6.2.2 apply to organizations and projects as stated in the boxes with the following additions:

> a) The requirements for infrastructure are defined.

Infrastructure requirements for SoS projects could be different from infrastructure requirements for CS projects. For example, physical facilities such as integration labs and test labs could be needed for interoperability testing for conformance to SoS standards.

> b) The infrastructure elements are identified and specified.

SoS could need additional project infrastructure elements that are not needed by any of the CS individually. There could be a need for ongoing review, monitoring, and evolution of the infrastructure to keep pace with CS changes across the SoS to maintain the SoS objectives (i.e., this could be a very dynamic activity; evolutionary development/support is likely).

> c) Infrastructure elements are developed or acquired.

Depending on the degree of managerial independence of the CS, the approach to developing and acquiring SoS project infrastructure elements could be quite different from systems.

> d) The infrastructure is available.

Because SoS and CS could be operating using different life cycle models and could be at different stages within their life cycles, the availability, robustness, and resiliency of SoS project infrastructure could be of greater concern than with the CS alone.

6.2.4 Portfolio management process

6.2.4.1 Purpose

The purpose of the Portfolio management process in ISO/IEC/IEEE 15288:2015, 6.2.3 is shown in the box.

> The purpose of the Portfolio Management process is to initiate and sustain necessary, sufficient and suitable projects in order to meet the strategic objectives of the organization.
>
> This process commits the investment of adequate organization funding and resources, and sanctions the authorities needed to establish selected projects. It performs continued assessment of projects to confirm they justify, or can be redirected to justify, continued investment.

The purpose of the Portfolio management process in ISO/IEC/IEEE 15288:2015, 6.2.3 applies as stated to SoS with the following additions.

In this context, a "portfolio" refers to a collection of projects, not a collection of CS or SoS.

Portfolio Management for organizations involved with SoS should address (to the extent possible, depending on the type of SoS management arrangements): 1) prioritization of SoS operational needs within the constraints of known and future changes to the CS and limited resources, 2)assignment of resources to SoS projects to meet the prioritized operational needs, and 3) consideration of the best phasing and sequencing of capability delivery and system changes to get the best outcome for SoS stakeholders.

6.2.4.2 Outcomes

The outcomes of the Portfolio management process in ISO/IEC/IEEE 15288:2015, 6.2.3 apply as stated in the boxes with the following additions:

a) Business venture opportunities, investments or necessities are qualified and prioritized.

Because the contribution of a CS to the SoS exceeds what the CS needs to address its own stakeholders, the business venture opportunities, investments, and necessities could have been under or incorrectly qualified and prioritized. Depending on operational and managerial independence, the approaches to qualifying and prioritizing could be different. For example, if the SoS governance does not have any ability to direct, then the influence to achieve the SoS capabilities needs to be created through understanding and communicating the mutual benefits within the SoS and its stakeholders, as well as the CS and their stakeholders. Disincentives should be addressed and minimized where possible.

b) Projects are identified.

Organizations managing a portfolio of projects could identify and decide to include SoS projects in their portfolios. In SoS context, the term "program" could be used instead of "project." Depending on operational and managerial independence, SoS projects would not directly manage resources in each CS project. Organizations involved with SoS could create projects to evolve and change the SoS to meet changing objectives or capability shortfalls. These projects could create new CS, modify extant CS, add new SoS elements, sustain extant SoS elements or address broad issues that are purely at the SoS level such as exploring options, developing roadmaps, defining standards, assessing performance or performing testing. Some SoS projects could include combinations of the above. Because SoS can contain system elements in addition to CS, resources and budgets to support those elements could be needed, regardless of the resources and budgets for the CS.

c) Resources and budgets for each project are allocated.

Depending on the degree of operational and managerial independence, additional resources and budgets could be needed to support an SoS beyond what was needed for the CS. The accounting for these resources and budgets could be different from the CS. Within an SoS, the resources and budget needed to implement new CS capabilities are estimated. Depending on the organizational arrangement, resources and budgets can be allocated from the SoS or by the CS owners.

d) Project management responsibilities, accountability, and authorities are defined.

Outcome applies as stated to SoS.

e) Projects meeting agreement and stakeholder requirements are sustained.

Depending on the degree of managerial and operational independence, organizations should consider that other organizations participating in the SoS could choose to sustain or not sustain projects regardless of whether agreements and stakeholder requirements are being met.

f) Projects not meeting agreement or satisfying stakeholder requirements are redirected or terminated.

Depending on the degree of managerial and operational independence, organizations should consider that other organizations participating in the SoS could redirect or terminate projects associated with CS without consideration of SoS stakeholder requirements and vice versa. SoS could terminate projects affecting the use of CS if the CS don't meet SoS needs. Likewise, CS could terminate participation in SoS that don't meet CS needs.

g) Projects that have completed agreements and satisfied stakeholder requirements are closed.

Additional or different criteria could be needed to assess whether projects have completed agreements and satisfied SoS and CS stakeholder requirements.

6.2.5 Human resource management process

6.2.5.1 Purpose

The purpose of the Human resource management process in ISO/IEC/IEEE 15288:2015, 6.2.4 is shown in the box.

The purpose of the Human Resource Management process is to provide the organization with necessary human resources and to maintain their competencies, consistent with business needs.

This process provides a supply of skilled and experienced personnel qualified to perform life cycle processes to achieve organization, project, and stakeholder objectives.

The purpose of the Human resource management process in ISO/IEC/IEEE 15288:2015, 6.2.4 applies as stated to SoS with the following addition.

Human resources for an SoS are those which address the activities/processes distinct from the CS processes. They could be provided by a separate engineering team and/or could be done cooperatively with the CS teams.

6.2.5.2 Outcomes

a) Skills required by projects are identified.

Skills required by SoS projects differ from other types of skills needed for CS. For example, within an SoS where CS collaborate or are managerially independent, skills related to influence instead of direction could be especially important. The SoS organization, if there is one, should identify any specific pool of expertise needed to maintain that SoS. These skills could reside within a CS organization. If so, their value to the SoS should be recognized by the CS. Alternatively, these skills could be developed separately from the CS organizations.

b) Necessary human resources are provided to projects.

Where there is an SoS authority, this organization's owners provide needed personnel, while the CS owners provide needed personnel for their CS.

c) Skills of personnel are developed, maintained or enhanced.

Outcome applies as stated to SoS.

d) Conflicts in multi-project resource demands are resolved.

Because the means for assessing the return on investment in an SoS project is immature, care should be taken when resolving conflicts related to resource demands. In some types of SoS, negotiation between CS can help resolve conflicts over resource demands, especially when resources are not centrally managed or controlled. Because the impact of resources on the SoS and CS could be unclear, care should be taken when resolving conflicts related to resource demands.

6.2.6 Quality management process

6.2.6.1 Purpose

The purpose of the Quality management process in ISO/IEC/IEEE 15288:2015, 6.2.5 is shown in the box.

The purpose of the Quality Management process is to assure that products, services and implementations of the quality management process meet organizational and project quality objectives and achieve customer satisfaction.

The purpose of the Quality management process in ISO/IEC/IEEE 15288:2015, 6.2.5 applies as stated to SoS.

6.2.6.2 Outcomes

The outcomes of the Quality management process in ISO/IEC/IEEE 15288:2015, 6.2.5 apply as stated in the boxes with the following additions:

a) Organizational quality management policies, objectives, and procedures are defined and implemented.

A quality management approach is established for SoS with a focus on the key elements of the SoS which impact SoS capability including the interactions among the CS and the end to end data and control flow across the CS and other SoS elements. SoS will typically depend on the CS for quality management of the CS. Depending on the degree of managerial independence, there could be some variation in the management of quality by the CS, ranging from highly prescriptive across all CS to completely absent in some CS. Organizations participating in an SoS should adjust their policies, objectives, and procedures to accommodate these realities and mitigate any associated risks.

b) Quality evaluation criteria and methods are established.

SoS quality evaluation criteria are developed with a specific focus on the SoS capabilities and as a result, additional or different quality evaluation criteria and methods could be needed for organizations participating in an SoS. An alignment approach could be needed to achieve the integrated SoS goals in the presence of variable quality systems. Depending on the degree of managerial independence, it could be difficult to establish criteria for integrated process performance.

c) Resources and information are provided to projects to support the operation and monitoring of project quality assurance activities.

In SoS, there could be resources available from the SoS organization (if one exists), otherwise CS quality management activities should address SoS quality management.

d) Quality assurance evaluation results are gathered and analyzed.

Depending on the degree of managerial independence, there could be some variation in the ability to obtain evaluation results from the SoS itself or from individual CS.

e) Quality management policies and procedures are improved based upon project and organizational results. NOTE These outcomes have been written to align with subclause 4.1 , General Requirements, of ISO 9001:2008. Refer to subclause 4.1 ISO 9001:2008 for information to establish a complete Quality Management System.

Organizations participating in an SoS should adjust their policies, objectives, and procedures to mitigate the challenges associated with the degree of managerial and operational independence of the CS.

6.2.7 Knowledge management process

6.2.7.1 Purpose

The purpose of the Knowledge management process in ISO/IEC/IEEE 15288:2015, 6.2.6 is shown in the box.

The purpose of the Knowledge Management process is to create the capability and assets that enable the organization to exploit opportunities to re-apply existing knowledge. This encompasses knowledge, skills, and knowledge assets, including system elements.

The purpose of the Knowledge management process in ISO/IEC/IEEE 15288:2015, 6.2.6 applies as stated to SoS.

6.2.7.2 Outcomes

The outcomes of the Knowledge management process in ISO/IEC/IEEE 15288:2015, 6.2.6 apply as stated in the boxes with the following additions:

a) A taxonomy for the application of knowledge assets is identified.

CS will have their own taxonomies and knowledge assets for their systems. The CS can collaborate or the SoS can define SoS-specific knowledge assets needed to align or map these to the knowledge assets for the CS as needed.

b) The organizational knowledge, skills, and knowledge assets are developed or acquired.

Organizational knowledge, skills, and knowledge assets could be developed or acquired by different organizations, particularly for different CS. SoS knowledge also needs to be gained. SoS knowledge assets could need to survive the individual CS, especially as CS enter or leave the participation in the SoS.

c) The organizational knowledge, skills, and knowledge assets are available.

Part of the organizational knowledge, skills, and knowledge assets corresponding to the SoS could be distributed across different organizations, including those responsible for CS. In addition, part of the

organizational knowledge, skills, and knowledge assets corresponding to the SoS could be common knowledge across two or more organizations related to the SoS and its CS.

d) Knowledge management usage data is gathered and analyzed.

Outcome applies as stated to SoS.

6.3 Technical management processes

6.3.1 General

ISO/IEC/IEEE 15288:2015, 6.3 contains general information on the application of system life cycle technical management processes to a system as shown in the box.

The Technical Management Processes are used to establish and evolve plans, to execute the plans, to assess actual achievement and progress against the plans and to control execution through to fulfillment. Individual Technical Management Processes may be invoked at any time in the life cycle and at any level in a hierarchy of projects, as required by plans or unforeseen events. The Technical Management Processes are applied with a level of rigor and formality that depends on the risk and complexity of the project.

The scope of a technical management process is the technical management of a project or its products, to include the system.

NOTE This set of technical management processes are performed so that system-specific technical processes can be conducted effectively. They do not comprise a management system or a comprehensive set of processes for project management, as that is not the scope of this standard.

The Technical Management Processes consist of the following:

a) Project Planning process;

b) Project Assessment and Control process;

c) Decision Management process;

d) Risk Management process;

e) Configuration Management process;

f) Information Management process;

g) Measurement process;

h) Quality Assurance process.

Project Planning and Project Assessment and Control are key to all management practices. These processes establish the general approach for managing a project or a process. The other processes in this group provide a specific focused set of tasks for performing to a specialized management objective. They are all evident in the management of any undertaking, ranging from a complete organization down to a single life cycle process and its tasks. In this International Standard, the project has been chosen as the context for describing processes. The same processes can also be applied in the performance of services.

ISO/IEC/IEEE 15288:2015, Annex G contains general information on the application of system life cycle processes to an SoS. Details of Technical management processes in ISO/IEC/IEEE 15288, G.3.4 are shown in the box.

In a typical system-of-interest, Technical Management Processes are concerned with managing the resources and assets allocated by organization management and with applying them to fulfill the agreements into which the organization or organizations enter. They relate to the management of projects, in particular to planning in terms of cost, timescales and achievements; to the checking of actions for compliance with plans and performance criteria; and to the identification and selection of corrective actions that recover shortfalls in progress and achievement. They are used to establish and perform technical plans for the project, manage information across the technical team, assess technical progress against the plans for the system products or services, control technical tasks through to completion, and to aid in the decision-making process (subclause 6.3).

The Technical Management Processes are also implemented at the level of the SoS and that of the constituent systems. Technical Management Processes are applied to the particular considerations of SoS engineering - planning, analyzing, organizing, and integrating the capabilities of a mix of existing and new systems into a system of systems capability. In parallel, the constituent systems organizations retain responsibility for engineering their systems and for their own Technical Management Processes.

The SoS organization addresses the Technical Management process as they apply across the SoS, while the processes are also implemented independently in the constituent system organizations. For configuration management for instance, constituent systems manage their own configurations while the SoS addresses configuration management as it applies to the mix of systems in the SoS. Risk is managed by the constituent systems based on assessment of risk as it applies to their outcomes while the SoS risk management looks at risk to the SoS.

Planning and Assessment and Control are key to all management practices (subclause 6.3; page 31); a key challenge in systems of systems engineering is the lack of control by the SoS organization over the processes for the constituent systems (particularly for acknowledged and collaborative SoS). Driven by their own organizational requirements, each of the constituent systems may be on a development or upgrade schedule that differs from the schedules of other constituent systems. The SoS organization must plan an integrated life cycle that recognizes the independent changes in the constituent systems, in addition to the SoS-initiated changes in a life cycle that treats the SoS as the SOI. This often involves the definition of stable intermediate forms that punctuate the SoS evolution with incremental capabilities added among the constituent systems.

The Technical management processes description from ISO/IEC/IEEE 15288 applies as stated to SoS with the following addition.

6.3.2 Project planning process

6.3.2.1 Purpose

The purpose of the Project planning process in ISO/IEC/IEEE 15288:2015, 6.3.1 is shown in the box.

The purpose of the Project Planning process is to produce and coordinate effective and workable plans.

This process determines the scope of the project management and technical activities, identifies process outputs, tasks and deliverables, establishes schedules for task conduct, including achievement criteria, and required resources to accomplish tasks. This is an on-going process that continues throughout a project, with regular revisions to plans.

NOTE The strategies defined in each of the other processes provide inputs and are integrated in the Project Planning process. The Project Assessment and Control process is used to assess whether the plans are integrated, aligned, and feasible.

The purpose of the Project planning process in ISO/IEC/IEEE 15288:2015, 6.3.1 applies as stated to SoS with the following addition.

SoS governance/management organizations could create projects to evolve and change the SoS to meet changing objectives or capability shortfalls. These projects could create new CS, modify extant CS, add new SoS elements, sustain extant SoS elements or address broad issues that are purely at the SoS level such as exploring options, developing roadmaps, defining standards, assessing performance or performing testing. Some SoS projects could include combinations of the above.

6.3.2.2 Outcomes

The outcomes of the Project planning process in ISO/IEC/IEEE 15288:2015, 6.3.1 apply as stated in the boxes with the following additions:

As a result of the successful implementation of the Project Planning process to an SoS:

a) Objectives and plans are defined.

SoS planning builds upon and influences the planning of its CS and system elements. Depending on the degree of governance and managerial independence within the SoS, agreement approaches for conflicting objectives, as well as approaches to anticipate, prevent, or react to the effects of CS not achieving or ceasing to achieve their individual objectives (i.e. abandonment or exile), should be defined. Publishing roadmaps can be used to influence the objectives and plans of potential CS.

b) Roles, responsibilities, accountabilities, authorities are defined.

SoS planning includes defining the roles responsibilities and authorities of the SoS organization (if any) as well as CS organizations in the SoS plans. Depending on the degree of governance and managerial independence, specific CS agreement and enforcement approaches should be defined as part of the large set of SoS agreements. In addition, plans for interim responsibilities or processes to define interim responsibilities should be defined to cope with the effects of CS not achieving or ceasing to achieve their individual objectives (e.g. higher CS priorities, abandonment or exile).

c) Resources and services necessary to achieve the objectives are formally requested and committed.

In SoS, resources could be available from the SoS organization (if one exists); otherwise, CS planning activities should address SoS Planning. Depending on the degree of governance and managerial independence, necessary resources and services should be agreed and committed instead of requested and committed.

d) Plans for the execution of the project are activated.

Outcome applies as stated to SoS.

6.3.3 Project assessment and control process

6.3.3.1 Purpose

The purpose of the Project assessment and control process in ISO/IEC/IEEE 15288:2015, 6.3.2 is shown in the box.

The purpose of the Project Assessment and Control process is to assess if the plans are aligned and feasible; determine the status of the project, technical and process performance; and direct execution to help ensure that the performance is according to plans and schedules, within projected budgets, to satisfy technical objectives.

This process evaluates, periodically and at major events, the progress and achievements against requirements, plans and overall business objectives. Information is provided for management action when significant variances are detected. This process also includes redirecting the project activities and tasks, as appropriate, to correct identified deviations and variations from other technical management or technical processes. Redirection may include re-planning as appropriate.

The purpose of the Project assessment and control process in ISO/IEC/IEEE 15288:2015, 6.3.2 applies as stated to SoS with the following additions.

In the context of SoS, "direct execution" could be better understood as coordination, collaboration, and influencing.

6.3.3.2 Outcomes

The outcomes of the Project assessment and control process in ISO/IEC/IEEE 15288:2015, 6.3.2 apply as stated in the boxes with the following additions:

As a result of the successful implementation of the Project Assessment and Control process to an SoS:

a) Performance measures or assessment results are available.

Outcome applies as stated to SoS.

b) Adequacy of roles, responsibilities, accountabilities, and authorities is assessed.

Depending on the governance and managerial independence of the SoS, adequacy of agreements and enforcement approaches should be assessed as well.

c) Adequacy of resources is assessed.

Outcome applies as stated to SoS.

d) Technical progress reviews are performed.

Depending on the governance independence of the SoS, it might not be possible to perform technical reviews of some of the CS, or part of them. However, it can be possible to conduct “proxy” reviews (i.e., without the CS owner present), but there could be little opportunity for any easy corrective action for any identified shortcomings.

e) Deviations in project performance from plans are investigated and analyzed.

Outcome applies as stated to SoS.

f) Affected stakeholders are informed of project status.

Outcome applies as stated to SoS.

g) Corrective action is defined and directed, when project achievement is not meeting targets.

Depending on the governance independence of the SoS, corrective action should be agreed upon between the governing and managing authorities of each CS, and collaboratively decided and executed instead of directed.

h) Project replanning is initiated, as necessary.

Outcome applies as stated to SoS.

i) Project action to progress (or not) from one scheduled milestone or event to the next is authorized.

Depending on governance and managerial independence of the SoS, action to progress (or not) could be agreed, recommended, or incentivized/penalized instead of authorized. SoS plans should be adjusted based on the current and planned states of the CS.

j) Project objectives are achieved.

Outcome applies as stated to SoS.

6.3.4 Decision management process

6.3.4.1 Purpose

The purpose of the Decision management process in ISO/IEC/IEEE 15288:2015, 6.3.3 is shown in the box.

The purpose of the Decision Management process is to provide a structured, analytical framework for objectively identifying, characterizing and evaluating a set of alternatives for a decision at any point in the life cycle and select the most beneficial course of action. NOTE 1 This process is used to resolve technical or project issues and respond to requests for decisions encountered during the system life cycle, in order to identify the alternative(s) that provides the preferred outcomes for the situation. The methods most frequently used for Decision Management are the trade study and engineering analysis. Each of the alternatives is assessed against the decision criteria (e.g., cost impact, schedule impact, programmatic constraints, regulatory implications, technical performance characteristics, critical quality characteristics, and risk). Results of these comparisons are ranked, via a suitable selection model, and are then used to decide on an optimal solution. Key study data, (e.g., assumptions and decision rationale) are typically maintained to inform decision-makers, and support future decision-making. NOTE 2 When it is necessary to perform a detailed assessment of a parameter for one of the criteria, the System Analysis process is employed to perform the assessment.

The purpose of the Decision management process in ISO/IEC/IEEE 15288:2015, 6.3.3 applies as stated to SoS.

6.3.4.2 Outcomes

The outcomes of the Decision management process in ISO/IEC/IEEE 15288:2015, 6.3.3 apply as stated in the boxes with the following additions:

As a result of the successful implementation of the Decision Management process to an SoS:

a) Decisions requiring alternative analysis are identified.

For SoS, decisions can affect multiple CS, so CS should be engaged in both the decision and analysis processes along with the SoS. There can be impacts on the CS which are beyond the purview of the SoS. Because of the constraints placed by existing CS, exploration of solutions could yield a higher variation in

alternatives than is expected for systems. Further, depending on the managerial independence of the CS, evaluation of technically viable alternatives could be not feasible due to individual objectives of the CS.

b) Alternative courses of action are identified and evaluated.

Depending on the managerial independence of the CS, evaluation of alternatives could be not feasible due to individual objectives of the CS. As a result, exploration of solutions could yield a higher variation in alternatives that is usually accustomed for systems.

c) A preferred course of action is selected.

Depending on the governance independence of the SoS, the notion of "preferred course of action" could be meaningless. Instead, the expected outcome could be an agreed or an incidental course of action or selection of alternative system.

d) The resolution, decision rationale and assumptions are identified.

Depending on the SoS strength of governance, the identification of the "resolution, decision rationale and assumptions" could range from stated and documented to implied.

6.3.5 Risk management process

6.3.5.1 Purpose

The purpose of the Risk management process in ISO/IEC/IEEE 15288:2015, 6.3.4 is shown in the box.

The purpose of the Risk Management process is to identify, analyze, treat and monitor the risks continually. The Risk Management process is a continual process for systematically addressing risk throughout the life cycle of a system product or service. It can be applied to risks related to the acquisition, development, maintenance or operation of a system. NOTE Risk is defined in ISO Guide 73:2009 as "The effect of uncertainty on objectives". This has an attached NOTE 1, "An effect is a deviation from the expected — positive and/or negative." A positive risk is sometimes commonly known as an opportunity, and addressed within the risk management process.

The purpose of the Risk management process in ISO/IEC/IEEE 15288:2015, 6.3.4 applies as stated to SoS.

6.3.5.2 Outcomes

The outcomes of the Risk management process in ISO/IEC/IEEE 15288:2015, 6.3.4 apply as stated in the boxes with the following additions:

As a result of the successful implementation of the Risk Management process to an SoS:

a) Risks are identified.

Risks faced by the SoS could be different from those faced by the CS. SoS risks could result from several CS that do not have the risk individually.

b) Risks are analyzed.

SoS risks could require analysis of the network of interoperating CS.

c) Risk treatment options are identified, prioritized, and selected.

Depending on the governance independence of the SoS, prioritization and selection could be impossible. Instead, risk treatment options and their planned implementation should be agreed upon or recommended. Their incidental execution as a byproduct of the actions of the projects developing the CS should be monitored. CS incentives could be needed to facilitate proper treatment of SoS risks.

d) Appropriate treatment is implemented.

Depending on the governance independence of the SoS, enforcing the implementation of risk treatment could be not feasible. Outcome applies as stated to SoS.

e) Risks are evaluated to assess changes in status and progress in treatment.

Outcome applies as stated.

6.3.6 Configuration management process

6.3.6.1 Purpose

The purpose of the Configuration management process in ISO/IEC/IEEE 15288:2015, 6.3.5 is shown in the box.

The purpose of Configuration Management (CM) is to manage and control system elements and configurations over the life cycle. CM also manages consistency between a product and its associated configuration definition.

The purpose of the Configuration management process in ISO/IEC/IEEE 15288:2015, 6.3.5 applies as stated to SoS.

6.3.6.2 Outcomes

The outcomes of the Configuration management process in ISO/IEC/IEEE 15288:2015, 6.3.5 apply as stated in the boxes with the following additions:

As a result of the successful implementation of the Configuration Management process to an SoS:

a) Items requiring configuration management are identified and managed.

SoS configuration management focuses on those elements which specifically relate to the SoS, while the CS retain configuration management of the details of their systems. SoS configuration items include CS and system elements, SoS functions allocated to the CS, interfaces between each CS and current protocols used to support each interface.

b) Configuration baselines are established.

The establishment of baselines for the SoS is dependent on the SoS classification and what, if any, agreements are in place. While cooperation from CS is helpful, it is not always possible, especially in loosely organized SoS. It could be possible to baseline or define compatibility across elements, e.g., CS1 version A is compatible with CS2 version B or C, and potentially include or encourage individual system features within the SoS to disallow interaction between elements which are not compatible.

c) Changes to items under configuration management are controlled.

In the context of SoS, “controlled” means monitored and recorded, not that there is control exercised into approving/rejecting/implementing the change itself.

Depending on the degree of managerial independence, changes to items under configuration management under the control of one CS could be uncontrolled from the perspective of another CS or the SoS.

Depending on the type of SoS there can be configuration management of some aspects and attributes of the CS (e.g., defense systems subject to certification of interoperability of some interfaces needed for SoS) but not all CS attributes. These attributes themselves can establish a baseline from the SoS point of view. If an interface specification is a part of a baseline and is used by a number of CS, upwards compatibility should be considered for each of the CS when the specification is changed. Failure to conform to that baseline could render the CS unable to participate in the SoS (e.g. defense platforms not meeting the interoperability criteria cannot participate in certain operations where the SoS features are necessary).

d) Configuration status information is available.

Outcome applies as stated to SoS.

e) Required configuration audits are completed.

Outcome applies as stated to SoS.

f) System releases and deliveries are controlled and approved.

Depending on the governance independence of the SoS, formal releases and deliveries of the SoS could be infeasible or not exist. Rather, they could occur incidentally, as its CS are released and delivered. Formal releases and deliveries of system elements, and interfaces, which are specific to the SoS should be controlled separately depending on the SoS management and governance.

6.3.7 Information management process

6.3.7.1 Purpose

The purpose of the Information management process in ISO/IEC/IEEE 15288:2015, 6.3.6 is shown in the box.

The purpose of the Information Management process is to generate, obtain, confirm, transform, retain, retrieve, disseminate and dispose of information, to designated stakeholders. Information management plans, executes, and controls the provision of information to designated stakeholders that is unambiguous, complete, verifiable, consistent, modifiable, traceable, and presentable. Information includes technical, project, organizational, agreement, and user information. Information is often derived from data records of the organization, system, process, or project.

The purpose of the Information management process in ISO/IEC/IEEE 15288:2015, 6.3.6 applies as stated to SoS.

6.3.7.2 Outcomes

The outcomes of the Information management process in ISO/IEC/IEEE 15288:2015, 6.3.6 apply as stated in the boxes with the following additions:

As a result of the successful implementation of the Information Management process to an SoS:

a) Information to be managed is identified.

The types of information to be managed can relate to the SoS itself, the governance of the SoS and the CS. SoS information management should be clearly defined and agreements made with the CS, where possible, to share the needed information.

b) Information representations are defined.

Representations of data should be negotiated and mapped; conversions necessary to translate information from the CS to the SoS should be defined.

c) Information is obtained, developed, transformed, stored, validated, presented, and disposed of.

SoS should respect individual CS confidentiality, security, and IP ownership, especially when agreements are informal or absent.

d) The status of information is identified.

Outcome applies as stated to SoS.

e) Information is available to designated stakeholders.

For an SoS, this could include the organizations of the CS. Some information from CS might not be available to SoS stakeholders or other CS stakeholders. Consideration should be given to availability of SoS information to individual CS, as this could be the primary means to influence CS behaviors.

6.3.8 Measurement process

6.3.8.1 Purpose

The purpose of the Measurement process in ISO/IEC/IEEE 15288:2015, 6.3.7 is shown in the box.

The purpose of the Measurement process is to collect, analyze, and report objective data and information to support effective management and demonstrate the quality of the products, services, and processes.

The purpose of the Measurement process in ISO/IEC/IEEE 15288:2015, 6.3.7 applies as stated to SoS.

6.3.8.2 Outcomes

The outcomes of the Measurement process in ISO/IEC/IEEE 15288:2015, 6.3.7 apply as stated in the boxes with the following additions:

As a result of the successful implementation of the Measurement process to an SoS:

a) Information needs are identified.

Information needs of both the SoS and the CS necessary for CS participation in the SoS are identified. Information needs of the CS, not needed by the SoS, are covered by ISO/IEC/IEEE 15288. Where possible, SoS and CS needs should be aligned to minimize the effects of SoS measurement on the CS.

b) An appropriate set of measures, based on the information needs are identified or developed.

Depending on the level of managerial and governance independence of the SoS and the CS, the set of measures should include secondary or non-nominal measures that can be used as alternative to primary or nominal measures to provide insight into understanding the effects of CS which are not achieving or have ceased to achieve their individual objectives (i.e. abandonment or exile). The definition of these measures can be accompanied by a description of the impact on the performance or capability of each CS, if applicable, and of the overall SoS.

c) Required data is collected, verified, and stored.

Depending on the level of managerial and governance independence of the SoS and the CS, collection, verification, and storage of data might not be possible. Alternative processes should be defined, such as sharing or mirroring (instead of data collection), approaches for providing trustworthiness (instead of verification), and conditions related to data access, e.g., access right expiration (instead of storage). Additional CS or SoS elements could also be added to assist the monitoring of the SoS.

d) The data is analyzed and the results interpreted.

Outcome applies as stated to SoS.

e) Information items provide objective information that support decisions.

Depending on the governance independence of the SoS, information provided by each CS could be subjective. In some cases, information items provide information according to pre-established agreements within the SoS that support decisions.

6.3.9 Quality assurance process

6.3.9.1 Purpose

The purpose of the Quality assurance process in ISO/IEC/IEEE 15288:2015, 6.3.8 is shown in the box.

The purpose of the Quality Assurance process is to help ensure the effective application of the organization's Quality Management process to the project. Quality Assurance focuses on providing confidence that quality requirements will be fulfilled. Proactive analysis of the project life cycle processes and outputs is performed to assure that the product being produced will be of the desired quality and that organization and project policies and procedures are followed.

The purpose of the Quality assurance process in ISO/IEC/IEEE 15288:2015, 6.3.8 applies as stated to SoS.

6.3.9.2 Outcomes

The outcomes of the Quality assurance process in ISO/IEC/IEEE 15288:2015, 6.3.8 apply as stated in the boxes with the following additions:

As a result of the successful implementation of the Quality Assurance process to an SoS:

a) Project quality assurance procedures are defined and implemented.

Depending on the governance independence of the SoS, quality assurance procedures for the SoS should be defined and implemented. Definition should include anticipated deviations at the CS that could result from non-resolvable conflicts between independently governed CS. In addition, the procedures should also include the provisions necessary for the SoS to cope with incidents not resolved by one or more of its CS.

b) Criteria and methods for quality assurance evaluations are defined.

Depending on the governance independence of the SoS, criteria and methods for quality assurance evaluations should be agreed upon. This agreement should identify i) the actors responsible for checking conformance to criteria, ii) the actors responsible for executing the methods, and iii) the information, data, and assumptions of each CS in relation to the planned evaluations.

c) Evaluations of the project's products, services, and processes are performed, consistent with quality management policies, procedures, and requirements.

Outcome applies as stated to SoS.

d) Results of evaluations are provided to relevant stakeholders.

Outcome applies as stated to SoS.

e) Incidents are resolved.

Depending on the governance independence of the SoS, incident resolution (including decision to resolve the issue) could need to be agreed upon between the governing and managing authorities of each CS. In some cases, incidents will be handled separately by each CS, without agreement between them.

f) Prioritized problems are treated.

Depending on the governance independence of the SoS, problem treatment, as well as definition of priorities, should be agreed upon between the governing and managing authorities of each CS.

6.4 Technical processes

6.4.1 General

ISO/IEC/IEEE 15288:2015, 6.4 contains general information on the application of system life cycle technical processes to a system as shown in the box.

The Technical Processes define the activities that enable organization and project functions to optimize the benefits and reduce the risks that arise from technical decisions and actions. These activities enable products and services to possess the timeliness and availability, the cost effectiveness, and the functionality, reliability, maintainability, producibility, usability and other qualities required by acquiring and supplying organizations. They also enable products and services to conform to the expectations or legislated requirements of society, including health, safety, security and environmental factors.

The Technical Processes consist of the following:

a) Business or Mission Analysis process;

b) Stakeholder Needs and Requirements Definition process;

c) System Requirements Definition process;

d) Architecture Definition process;

e) Design Definition process;

f) System Analysis process;

g) Implementation process;

h) Integration process;

i) Verification process;

j) Transition process;

k) Validation process;

l) Operation process;

m) Maintenance process;

n) Disposal process.

NOTE 1 For software and hardware system elements, these processes are applied at recursively lower levels for system definition and recursively higher levels for system realization for stakeholder needs and requirements definition, system requirements definition, architecture definition, design definition, system analysis, integration, verification and validation.

NOTE 2 These processes are often performed concurrently, iterating between one another to establish a solution that is balanced with respect to requirements, critical performance measures, and critical quality characteristics. At any level of abstraction, system requirements and models are made consistent via iterations of applicable technical processes. When requirements and models are not directly capable of being implemented, the same processes are repeated recursively at a more detailed level, e.g., the next lower level of the system hierarchy.

NOTE 3 The concept of life cycle stages and the application of these processes in any stage are described in detail in ISO/IEC TR 24748-1 (IEEE Std 24748-1-2011). It has a complete set of example stages and stage outcomes for the enactment of technical processes within a system life cycle.

NOTE 4 Interface Management is a set of activities that cut across the systems engineering processes. These are cross-cutting activities of the Technical and Technical Management processes that apply and track as a specific view of the processes and system. See Annex E of this standard for an example Interface Management Process View and the INCOSE Systems Engineering Handbook, Version 4, section 9.6 for more information.

ISO/IEC/IEEE 15288:2015, Annex G contains general information on the application of system life cycle processes to an SoS. Details of Technical processes in ISO/IEC/IEEE 15288:2015, G.3.5 are shown in the box.

Technical Processes are concerned with technical actions throughout the life cycle. They transform the needs of stakeholders first into a product and then, by applying that product, provide a sustainable service, when and where needed in order to achieve customer satisfaction. The Technical Processes are applied in order to create and use a system, whether it is in the form of a model or is a finished product, and they apply at any level in a hierarchy of system structure (Subclause 6.4).

As with the other processes when applied to SoS, Technical Processes are implemented for both the SoS and constituent systems; in some cases, the SoS implementation is by means of conduct of the constituent system processes rather than for the SoS as a whole.

Business or Mission Analysis for an SoS looks across the full SoS business and mission environment. To the degree the constituent system was developed to operate in that space, the Business or Mission Analysis for the systems of system and constituent systems will be largely shared. The objective is to determine the best means to provide the desired capability.

Stakeholder Needs and Requirements Definition will focus on the top level SoS, but also consider how the disparate needs of the stakeholders for the individual systems may lead to constraints on the system of systems.

System Requirements Definition for the SoS tends to be defined at the level needed to satisfy stakeholder needs and mission objectives, to be translated into requirements for the constituent systems with the SoS serving as "stakeholder" for new requirements for the constituent systems.

The Architecture for the SoS is a framework for organizing and integrating the capabilities of a mix of existing and new systems into a SoS capability, leaving the architectures of the constituent systems to their organizations. Because the constituent systems in an SoS usually predate the SoS, SoS Architecture Definition often begins with the de facto architecture of the SoS. Architecture alternatives are then examined in order to frame stakeholder concerns and meet top level system of system requirements, and to recognize the effect of new requirements for the constituent systems and accommodate the constituent system architecture constraints.

The Design Definition process provides sufficient detailed data and information to enable the SoS implementation. This involves collaboration with the constituent systems who will conduct their own design trades to identify the approach to address SoS requirements as they apply to their system. These are the responsibility of the constituent system organization and Implementation is a done by the constituent system with the SoS organization in a monitoring role.

Integration, Verification, Transition, Validation are all done by the constituent systems for the changes they implement to support requirements generated by the SoS. These processes also apply to the SoS when the upgraded constituent systems are integrated into the SoS and performance is verified and validated. The independent and asynchronous nature of constituent systems in an SoS pose challenges to effective implementation of these processes as implemented in a traditional SOI. It may be that the SoS-level evaluations can only be performed in the operational environment, in which case precautionary measures should be considered to avoid adverse SoS-behavior.

Finally, the Operations, Maintenance and Disposal Processes tend to be implemented by the constituent systems, given their management and operational independence. There may be SoS-level interactions to facilitate those processes.

The Technical processes description from ISO/IEC/IEEE 15288 apply as stated with the following addition:

The Technical processes are highly iterative and concurrent. In some cases, there could be “waves” of SoS revision. In other cases, SoS changes could occur continually, with many Technical processes operating on a continuous basis to implement evolutionary change.

SoS Technical processes could be implemented by an SoS owner (if any) or by individual CS owners based on their local, partial view of the SoS. In the latter case, new Collaboration and Competition processes could apply.

6.4.2 Business or mission analysis process

6.4.2.1 Purpose

The purpose of the Business or mission analysis process in ISO/IEC/IEEE 15288:2015, 6.4.1 is shown in the box.

> The purpose of the Business or Mission Analysis process is to define the business or mission problem or opportunity, characterize the solution space, and determine potential solution class(es) that could address a problem or take advantage of an opportunity.
>
> NOTE 1 Business and Mission Analysis is related to the organization encompassing all stakeholders concerned by the activities of the system life cycle. This process interacts with the organization's strategy, which is generally outside the scope of 15288. The results of the organization's strategic analysis include the organizational Concept of Operations, strategic goals and plans, new market or mission elements, and identified problems and opportunities. The organization's strategy establishes the context within which the business or mission analysis is performed. The organizational Concept of Operations relates to the leadership's intended way of operating the organization. It describes the organization's assumptions and how it intends to use the system to be developed, existing systems, and possible future systems in support of an overall operation or series of operations of the business. In the case that the organization is the system-of- interest, the organization's strategy is part of the system definition.
>
> NOTE 2 This process has application through the life of the system solution and is revisited if there are changes in the environment, needs, or other drivers.
>
> NOTE 3 In some domains, this relates to the concept of identifying and analyzing capabilities that are needed or desired by the organization. This process focuses on the necessary capabilities and interacts with the Portfolio Management process for identifying the trade space that can address the capability. The identified problems or opportunities are often translated into target capabilities. As applicable within a given domain, the problem or opportunity space includes the target capabilities.

The purpose of the Business or mission analysis process in ISO/IEC/IEEE 15288:2015, 6.4.1 applies as stated to SoS with the following addition.

The business or mission analysis process for SoS should address (to the extent possible, depending on the type of SoS management arrangements):

a) definition of the SoS objectives and SoS target states(s), noting that these could be defined at multiple future times with varying fidelity;

b) analysis of the priorities to address capability gaps;

c) analysis of potential alternatives and courses of action to address SoS operational needs, taking into account known plans for individual CS;

d) evaluation of the SoS capacity to satisfy stakeholders.

6.4.2.2 Outcomes

The outcomes of the Business or mission analysis process in ISO/IEC/IEEE 15288:2015, 6.4.1 apply as stated in the boxes with the following additions:

As a result of the successful implementation of the Business or Mission Analysis process to an SoS:

> a) The problem or opportunity space is defined.

Problems and opportunities addressed by SoS are typically broader and more complex than those addressed by systems, so the tasks related to defining them are typically described at a higher level of abstraction and they tend to be more varied and likely also more complicated. These are typically

characterized in terms of higher-level capability objectives which can serve as the bases for assessing alternative approaches to address these capabilities.

b) The solution space is characterized.

The characterization of a solution space that involves an SoS will include the candidate CS, how each CS supports the new problem or opportunity, and any constraints these CS could impose on the solution space. Often, SoS capabilities are addressed by a set of existing systems. A logical starting point for assessing the SoS solution space is to begin with the current systems and the way they are addressing the SoS capabilities to understand current capability gaps and constraints. An SoS could be identified as a potential solution class or classes due to the need to integrate with existing systems.

c) Preliminary operational concepts and other concepts in the life cycle stages are defined.

Since many SoS consist of existing CS that already have operational and other concepts, the SoS's operational and other concepts could be constrained. The ability to change or influence these concepts could vary depending on the degree of managerial independence and the flexibility or range of concepts possible in the extant CS.

d) Candidate alternative solution classes are identified and analyzed.

By analyzing current SoS capabilities (if one exists), capability gaps can be identified, and the sources of these gaps provide the basis for identifying potential changes which could be made to improve the achievement of the objectives. The ability to identify candidate alternative solution classes is influenced by the depth and breadth of information about potential new and current CS, how they are used to address capability objectives, their interdependencies, and their ability to meet capability objectives. Alternatives could include the use of CS in different ways, additions of different or new CS or non-system systems elements, or changes in the functionality or capacity of SoS.

e) The preferred candidate alternative solution class(es) are selected.

For SoS, multiple alternative solutions could be viable. Care should be taken to establish criteria for the selection that addresses SoS and CS constraints and other considerations.

f) Any enabling systems or services needed for business or mission analysis are available.

Outcome applies as stated to SoS.

g) Traceability of business or mission problems and opportunities and the preferred alternative solution classes is established.

Outcome applies as stated to SoS.

6.4.3 Stakeholder needs and requirements definition process

6.4.3.1 Purpose

The purpose of the Stakeholder needs and requirements definition process in ISO/IEC/IEEE 15288:2015, 6.4.2 is shown in the box.

The purpose of the Stakeholder Needs and Requirements Definition process is to define the stakeholder requirements for a system that can provide the capabilities needed by users and other stakeholders in a defined environment.

It identifies stakeholders, or stakeholder classes, involved with the system throughout its life cycle, and their needs. It analyzes and transforms these needs into a common set of stakeholder requirements that express the intended interaction the system will have with its operational environment and that are the reference against which each resulting operational capability is validated. The stakeholder requirements are defined considering the context of the system-of-interest with the interoperating systems and enabling systems.

The purpose of the Stakeholder needs and requirements definition process in ISO/IEC/IEEE 15288:2015, 6.4.2 applies as stated to SoS with the following addition.

Depending on the type of SoS management arrangements, the stakeholder needs and requirements definition process for SoS should address:

a) selection/recommendation of new capabilities for inclusion in upgrades to one or more CS;

b) identification of needs and requirements to resolve SoS issues in the extant SoS and CS.

c) creation of new system elements.

6.4.3.2 Outcomes

The outcomes of the Stakeholder needs and requirements definition process in ISO/IEC/IEEE 15288:2015, 6.4.2 apply as stated in the boxes with the following additions:

As a result of the successful implementation of the Stakeholder Needs and Requirements Definition process to an SoS:

a) Stakeholders of the system are identified.

For SoS, it is not always possible to identify all stakeholders, especially given that CS will continue to have managerial and operational independence as well as interdependence. Stakeholders of the SoS as a whole and individual CS stakeholders should be considered. It is important to be cognizant of the key CS stakeholder needs which could align or conflict with the SoS objectives, since these could constrain the CS in making any changes to meet the need of the SoS.

The owner, maintainer, operator, and data owner of any CS within the SoS could be stakeholders in the SoS engineering effort. Documenting these stakeholders is complicated given that a CS will continue to have managerial and operational independence as well as interdependence. The difficulty in maintaining this list does not eliminate the need for it. These roles should be addressed for each CS, even if the preliminary information is vague.

b) Required characteristics and context of use of capabilities and concepts in the life cycle stages, including operational concepts, are defined.

Understanding that each CS will have its own operational concepts and development lifecycles that evolve independently, it is important to document where each system is within its lifecycle to understand its potential role in the proposed SoS. Understanding CS lifecycles will serve to identify potential injection points within the SoS lifecycle. There could be different “epochs” (periods of time) where the specific CS vary and the SoS can achieve different/evolving capability. Identifying any of these epochs or points in time (effectively different capability states) and any considerations relating to the transition between them would be useful and provide a basis to identify the SoS "change" elements that should be coordinated or encouraged.

c) Constraints on a system are identified.

Constraints on the SoS should be identified since these impact options for SoS evolution. Because many SoS consist of CS that already exist, these CS could be a major source of constraints on the SoS since typically they have their own objectives, lifecycle and stakeholders as well as their own constraints, all of which could affect how much CS change is possible to support SoS needs.

d) Stakeholder needs are defined.

Because it is not always possible to identify all stakeholders, definition of stakeholder needs is likely to be incomplete. The SoS should plan to accommodate emergent stakeholders and their needs and/or the constraints they impose on SoS operation and evolution.

e) Stakeholder needs are prioritized and transformed into clearly defined stakeholder requirements.

Because it is not always possible to identify all stakeholders and their needs, prioritizing them and transforming them into stakeholder requirements is likely to be incomplete. The needs of different stakeholders could conflict or be opposed to each other. CS needs could conflict with SoS needs. The SoS should plan to accommodate evolving stakeholder priorities and fluid requirements.

f) Critical performance measures are defined.

Critical performance measures should exist for the SoS in addition to the CS. The critical measures for the CS necessary to support the SoS could be different from those necessary for CS.

g) Stakeholder agreement that their needs and expectations are reflected adequately in the requirements is achieved.

Although SoS and CS stakeholders should strive for consensus, they could disagree on the needs, expectations, and requirements for the SoS. Depending on the degree of managerial and operational independence, agreement might not be required of all CS stakeholders for effective definition of the SoS, but disagreement could inhibit the CS's integration into the SoS, or it could cause the SoS to identify alterative architecture or design options to meet the SoS capability objectives.

h) Any enabling systems or services needed for stakeholder needs and requirements are available.

Outcome applies as stated to SoS.

i) Traceability of stakeholder requirements to stakeholders and their needs is established.

Outcome applies as stated to SoS.

6.4.4 System requirements definition process

6.4.4.1 Purpose

The purpose of the System requirements definition process in ISO/IEC/IEEE 15288:2015, 6.4.3 is shown in the box.

The purpose of the System Requirements Definition process is to transform the stakeholder, user-oriented view of desired capabilities into a technical view of a solution that meets the operational needs of the user.

This process creates a set of measurable system requirements that specify, from the supplier's perspective, what characteristics, attributes, and functional and performance requirements the system is to possess, in order to satisfy stakeholder requirements. As far as constraints permit, the requirements should not imply any specific implementation.

The purpose of the System requirements definition process in ISO/IEC/IEEE 15288:2015, 6.4.3 applies as stated to SoS with the following additions.

For the SoS, the System Requirements Definition process transforms the stakeholder view of desired capabilities into a useful SoS system definition for implementation. This process creates a set of SoS characteristics, attributes, functions, and performance that the SoS should possess to satisfy the stakeholder requirements.

In some cases, the SoS system definition statements could be identical to the capabilities defined in the stakeholder requirements. In other cases, there could be a more detailed view available within the available time frame.

For some SoS, individual CS owners could perform System Requirements Definition for the SoS, with each CS owner creating their own version of the SoS requirements for their own purposes.

For some SoS, it could be feasible to collect and analyze the requirements for each CS to understand how the SoS requirements align to the CS requirements, and vice versa. For other types of SoS, the CS organizations could be unwilling to disclose this information.

6.4.4.2 Outcomes

The outcomes of the System requirements definition process in ISO/IEC/IEEE 15288:2015, 6.4.3 apply as stated in the boxes with the following additions:

As a result of the successful implementation of the System Requirements Definition process to an SoS:

a) The system description, including system interfaces, functions and boundaries, for a system solution is defined.

For an SoS, the description, interfaces, functions, and boundaries could change over time. SoS that consist of CS that are contingent or redundant could affect the description, interfaces, functions, and boundaries. Often, there is an existing set of CS supporting the SoS capabilities. Analysis of the current SoS to meet user capabilities can provide the basis for identifying SoS requirements – that is shortfalls in capability that could be addressed by changes in the SoS. So, for an SoS the system description includes both the current SoS instantiation and the shortfalls or gaps in meeting capability objectives.

Some SoS could be instantiated with different sets of CS under different circumstances, and the description should support this situation. The SoS description should clarify what is covered through ISO/IEC/IEEE 21839 and to what extent the SoS and CS are potentially affected.

b) System requirements (functional, performance, process, non-functional, and interface) and design constraints are defined.

As with systems, SoS requirements and design constraints can change over time. Once an SoS is implemented in some form, SoS requirements are reflected in gaps between current capabilities and desired capabilities. The SoS (depending on its type) should define those partial new requirements for each CS that are necessary to create the desired SoS behavior. However, the SoS would not need to define CS requirements that are not essential to the SoS.

SoS definition of new requirements for CS does not always mean that a CS organization will accept and implement those requirements. This could mean that the SoS cannot meet its objectives or that particular CS cannot remain part of the SoS in the same capacity.

c) Critical performance measures are defined.

Critical performance measures for SoS address the measurement of delivery of SoS capabilities under various situations. These can be translated into critical measures for CS in support of the SoS, but these measures could be different from those necessary for independent operation of the CS.

d) The system requirements are analyzed.

Analysis of SoS gaps is based on identifying alternative approaches to filling the gaps whether by changing SoS operations, by changing the composition of the SoS (new or added CS, added CS functions or capacity, new or updated system elements). Along with an assessment of the operation and technical feasibility of candidate options, the SoS can be analyzed to verify if these changes are made to such a degree that it will affect the ability to meet SoS capability objectives.

e) Any enabling systems or services needed for system requirements definition are available.

Outcome applies as stated to SoS.

f) Traceability of system requirements to stakeholder requirements is developed.

SoS stakeholder requirements could trace to SoS capability objectives and CS requirements. Likewise, CS stakeholder requirements could trace to multiple SoS requirements.

SoS requirements could conflict with or not align well to existing CS requirements. CS requirements could conflict with or not align well to existing SoS requirements.

6.4.5 Architecture definition process

6.4.5.1 Purpose

The purpose of the Architecture definition process in ISO/IEC/IEEE 15288:2015, 6.4.4 is shown in the box.

The purpose of the Architecture Definition process is to generate system architecture alternatives, to select one or more alternative(s) that frame stakeholder concerns and meet system requirements, and to express this in a set of consistent views. Iteration of the Architecture Definition process with the Business or Mission Analysis process, System Requirements Definition process, Design Definition process, and Stakeholder Needs and Requirements Definition process is often employed so that there is a negotiated understanding of the problem to be solved and a satisfactory solution is identified. The results of the Architecture Definition process are widely used across the life cycle processes. Architecture definition may be applied at many levels of abstraction, highlighting the relevant detail that is necessary for the decisions at that level.

NOTE 1 System architecture deals with fundamental principles, concepts, properties, and characteristics and their incorporation into the system-of-interest. Architecture definition has more uses than as merely a driver (or part of) design. Refer to ISO/IEC/IEEE 42010:2011 for more information about architecture description and the uses and nature of architecture.

NOTE 2 The Architecture Definition process supports identification of stakeholders and their concerns. As the process unfolds, insights are gained into the relation between the requirements specified for the system and the emergent properties and behaviors of the system that arise from the interactions and relations between the system elements. The Design Definition process (see subclause 6.4.5), on the other hand, is driven by requirements that have been vetted through the architecture and more detailed analyses of feasibility. Architecture focuses on suitability, viability, and desirability, whereas design focuses on compatibility with technologies and other design elements and feasibility of construction and integration. An effective architecture is as design-agnostic as possible to allow for maximum flexibility in the design trade space. An effective architecture also highlights and supports trade-offs for the Design Definition process and possibly other processes such as Portfolio Management, Project Planning, System Requirements Definition, and Verification.

NOTE 3 In product line architectures, the architecture is necessarily spanning across several designs. The architecture serves to make the product line cohesive and helps ensure compatibility and interoperability across the product line. Even for a single product system, the design of the product will likely change over time while the architecture remains constant.

The purpose of the Architecture definition process in ISO/IEC/IEEE 15288:2015, 6.4.4 applies as stated to SoS with the following additions.

The architecture of SoS focuses on the critical functionality of the SoS elements (CS and system elements, their interactions, and any cross-cutting critical functionality, e.g. timing, geospatial representations) rather than deeply diving into the inside architecture of CS. While systems are often described in terms of hierarchies with decomposition among the various levels, SoS are often described as more general networks of systems with complex interconnections that have been composed to form the SoS. The SoS architecture could be based on partial information and could represent only a known portion of the SoS. The SoS architecture could include and define system elements that are not part of any CS. The evolutionary nature of SoS makes the architecture definition fluid over time. While some aspects of the architecture could have enduring value, other aspects change and should be re-evaluated frequently. In addition, for those SoS where there could be different compositions of elements deployed under different circumstances, the architecture should accommodate this characteristic of SoS which further differentiates them from other systems.

6.4.5.2 Outcomes

The outcomes of the Architecture definition process in ISO/IEC/IEEE 15288:2015, 6.4.4 apply as stated in the boxes with the following additions:

As a result of the successful implementation of the Architecture Definition process to an SoS:

a) Identified stakeholder concerns are addressed by the architecture.

SoS architectures should reflect the needs of the SoS stakeholders for the SoS capabilities. However, it is also important that the architectures respect the needs of the CS stakeholders which could be affected by CS participation in the SoS. This includes the objective of SoS architectures which address SoS needs but impinges on the CS as little as possible allowing them to evolve to meet their user needs without affecting the SoS or the other CS. SoS architectures could change over time as CS are added, modified, or removed from the SoS. SoS architectures could be affected by CS architectures.

b) Architecture viewpoints are developed.

For SoS, architecture viewpoints that address the CS's perspective on the SoS facilitate communication. Depending on the degree of managerial and operational independence, the CS perspectives can be important.

c) Context, boundaries, and external interfaces of the system are defined.

For an SoS, the context, boundaries, and external interfaces could change over time as CS join and leave the SoS.

d) Architecture views and models of the system are developed.

Outcome applies as stated to SoS.

e) Concepts, properties, characteristics, behaviors, functions, or constraints that are significant to architecture decisions of the system are allocated to architectural entities.

Due to changes over time to the SoS, the allocation to architectural elements could change over time as well. Identifying those architectural elements necessary to create the desired SoS behavior is a key part of the SoS architecture definition. The SoS could define abstract classes of CS that (from the SoS perspective) appear the same and, for each of these classes, define the necessary constraints to achieve the expected SoS behavior.

f) System elements and their interfaces are identified.

For SoS, system elements are the CS, which could have well-defined interfaces. Additional elements and interfaces should be defined to clarify what those elements are and which actors they interface to.

g) Architecture candidates are assessed.

Making changes to the SoS architecture is one key option to addressing capability gaps in SoS, making assessment of architecture alternatives a key SoSE activity. The SoS architecture could evolve over time, so assessment of the impact of alternative architectures is an important part of the decision analysis for an SoS. By comparing architectures in terms of their impact on capability objectives, SoSE addresses options for changes to meet user needs. In assessing architecture options, it is important to assess the impact on the CS, since architecture options could require changes in the CS. Potential changes to CS should be taken into consideration when assessing architecture changes. Depending on the degree of operational and managerial independence, and the potential for CS to join or leave an SoS, the resiliency of the architectures could be important considerations in the assessment.

h) An architectural basis for processes throughout the life cycle is achieved.

Effectively managing the SoS architecture over time is key to SoS. A stable and open architecture can facilitate changes in CS without impacting the SoS or the other CS. Changes in the SoS architecture which impact the CS should be coordinated. To the extent possible, and subject to the degree of managerial and operational independence, the life cycles of the CS should be synchronized with the SoS life cycle.

i) Alignment of the architecture with requirements and design characteristics is achieved.

SoS architecture is based on how the CS are connected to form the SoS. Insight into the architectures of the CS could be relevant.

j) Any enabling systems or services needed for architecture definition are available.

Outcome applies as stated to SoS.

k) Traceability of architecture elements to stakeholder and system requirements is developed.

Outcome applies as stated to SoS.

6.4.6 Design definition process

6.4.6.1 Purpose

The purpose of the Design definition process in ISO/IEC/IEEE 15288:2015, 6.4.5 is shown in the box.

The purpose of the Design Definition process is to provide sufficient detailed data and information about the system and its elements to enable the implementation consistent with architectural entities as defined in models and views of the system architecture.

NOTE 1 The Architecture Definition process, supports identification of stakeholders and their concerns. Through the use of the process, insights are gained into the relation between the requirements specified for the system and the emergent properties and behaviors of the system that arise from the interactions and relations between the system elements. The Design Definition process, on the other hand, is driven by requirements that have been vetted through the architecture and more detailed analyses of feasibility. Architecture focuses on suitability, viability, and desirability, whereas design focuses on compatibility with technologies and other design elements and feasibility of construction and integration. An effective architecture is as design-agnostic as possible to allow for maximum flexibility in the design trade space.

NOTE 2 Design definition considers any applicable technologies and their contribution to the system solution. Design provides the 'implement-to' level of the definition, such as drawings and detailed design descriptions.

NOTE 3 This process provides feedback to the system architecture to consolidate or confirm the allocation, partitioning and alignment of architectural entities to system elements that compose the system.

The purpose of the Design definition process in ISO/IEC/IEEE 15288:2015, 6.4.5 applies as stated to SoS with the following additions.

The system elements of an SoS could be CS or specific system elements that are not part of any CS. Sometimes an SoS will require developing a completely new CS, using an existing CS without changes, or making changes to an existing CS.

With a long SoS life cycle, multiple design definitions could be created that implement changes into the SoS on a time-phased basis. Because some CS pre-exist the SoS, sometimes by decades of time, SoS Design Definition could include desired changes to a CS or could have to accept the CS design and capabilities as is. SoS Design Definition should also include time phasing of the CS implementations, to ensure that CS capabilities are (a) available when needed and (b) compatible with each other at all points in time.

In an SoS, design refers to the selection and adaptation of the elements of the SoS, that is, the CS or other system elements that can be necessary to facilitate interaction of the CS in the SoS.

6.4.6.2 Outcomes

The outcomes of the Design definition process in ISO/IEC/IEEE 15288:2015, 6.4.5 apply as stated in the boxes with the following additions:

As a result of the successful implementation of the Design Definition process to an SoS:

a) Design characteristics of each system element are defined.

Design in an SoS is based on identifying CS to support the SoS functions and interfaces between the elements specified in the SoS architecture. This provides the framework for assessing CS supporting the SoS capabilities, for assessing changes to CS and system elements, and for assessing changes or new or modified CS and system elements.

Depending on the degree of managerial independence, and other issues such as commercial sensitivities, organizations managing CS could be unwilling to fully disclose design information. However, SoS do not necessarily need a full definition of CS designs but are only concerned with the external characteristics of the CS that enable the SoS capabilities to be met. It is important to have enough CS design information to understand their behavior without necessarily understanding how CS achieve it. An overarching design for the SoS could be needed. This assessment could identify changes in CS which would be needed for them to participate effectively in the SoS.

b) System requirements are allocated to system elements.

In effect, the SoS architecture provides the high-level SoS requirements. Identifying and assessing CS for participation in an SoS is based on an understanding of the degree to which the systems provide critical functionality or services to meet SoS needs and the degree to which the system can operate with other systems in the SoS providing needed information and interfaces, as well as support cross-cutting functions critical to the SoS (e.g., geospatial referencing, timing, etc.). The selection of the set of CS to meet SoS needs is, in effect, allocating systems to SoS requirements. A similar process is applied to assess how well current CS and system elements are supporting SoS capability needs.

c) Design enablers necessary for design definition are selected or defined.

Outcome applies as stated to SoS.

d) Interfaces between system elements composing the system are defined or refined.

In an SoS, the systems interfaces are incorporated in the SoS architecture. The SoS design process focuses on assessing the ability of CS and system elements, either current or proposed, to implement the interfaces to meet SoS needs.

e) Design alternatives for system elements are assessed.

Alternative CS should be assessed.

f) Design artifacts are developed.

Additional design artifacts could be needed for SoS, including overarching design artifacts for the SoS, as well as interfaces to existing CS design artefacts. Design artifacts could already exist for CS, but they might not be in a form suitable for use by the SoS. However, depending on the degree of managerial independence, organizations managing CS could be unwilling to release such information.

g) Any enabling systems or services needed for design definition are available.

Outcome applies as stated to SoS.

h) Traceability of the design characteristics to the architectural entities of the system architecture is established.

Outcome applies as stated to SoS.

6.4.7 System analysis process

6.4.7.1 Purpose

The purpose of the System analysis process in ISO/IEC/IEEE 15288:2015, 6.4.6 is shown in the box.

> The purpose of the System Analysis process is to provide a rigorous basis of data and information for technical understanding to aid decision-making across the life cycle.
>
> The System Analysis process applies to the development of inputs needed for any technical assessment. It can provide confidence in the utility and integrity of system requirements, architecture, and design. System analysis covers a wide range of differing analytic functions, levels of complexity, and levels of rigor. It includes mathematical analysis, modeling, simulation, experimentation, and other techniques to analyze technical performance, system behavior, feasibility, affordability, critical quality characteristics, technical risks, life cycle costs, and to perform sensitivity analysis of the potential range of values for parameters across all life cycle stages. It is used for a wide range of analytical needs concerning operational concepts, determination of requirement values, resolution of requirements conflicts, assessment of alternative architectures or system elements, and evaluation of engineering strategies (integration, verification, validation, and maintenance). Formality and rigor of the analysis will depend on the criticality of the information need or work product supported, the amount of information/data available, the size of the project, and the schedule for the results.
>
> NOTE This process is often used in conjunction with the Decision Management process.

The purpose of the System analysis process in ISO/IEC/IEEE 15288:2015, 6.4.6 applies as stated to SoS.

6.4.7.2 Outcomes

The outcomes of the System analysis process in ISO/IEC/IEEE 15288:2015, 6.4.6 apply as stated in the boxes with the following additions:

As a result of the successful implementation of the System Analysis process to an SoS:

a) System analyses needed are identified.

SoS System Analysis could rely on both actual and predicted data. Because many CS pre-exist the SoS, actual data can be available from their operation. For other aspects of the SoS, however, predictive data will be necessary. For some SoS, the System Analysis process could be performed by each CS owner to support CS-level Decision Management with SoS impacts. Each CS owner could create different analyses and different results based on different viewpoints. The decisions resulting from these analyses could conflict at the SoS level. Depending on the degree of managerial and operational independence, resolution of such conflicts could be very challenging.

b) System analysis assumptions and results are validated.

SoS assumptions and results related to operational and managerial independence should be validated. Measuring points and instrumentation should be added within the SoS elements (within some CS and other elements, or perhaps as elements in their own right) to provide the data to validate analysis or models. The data are likely to be sparser and provide less certainty than that available within each CS.

c) System analysis results are provided for decisions.

Outcome applies as stated to SoS.

d) Any enabling systems or services needed for system analysis are available.

Outcome applies as stated to SoS.

e) Traceability of the system analysis results is established.

Outcome applies as stated to SoS.

6.4.8 Implementation process

6.4.8.1 Purpose

The purpose of the Implementation process in ISO/IEC/IEEE 15288:2015, 6.4.7 is shown in the box.

The purpose of the Implementation process is to realize a specified system element.

This process transforms requirements, architecture, and design, including interfaces, into actions that create a system element according to the practices of the selected implementation technology, using appropriate technical specialties or disciplines. This process results in a system element that satisfies specified system requirements (including allocated and derived requirements), architecture, and design. NOTE This applies to both a single element (concept and development stage) and production run (as in production stage). It also can apply in the resolution of changes needed in the Support stage.

The purpose of the Implementation process in ISO/IEC/IEEE 15288:2015, 6.4.7 applies as stated to SoS with the following addition.

SoS are typically implemented by composing existing and modified CS and other system elements to provide new capabilities.

6.4.8.2 Outcomes

The outcomes of the Implementation process in ISO/IEC/IEEE 15288:2015, 6.4.7 apply as stated in the boxes with the following additions:

As a result of the successful implementation of the Implementation process to an SoS:

a) Implementation constraints that influence the requirements, architecture, or design are identified.

SoS often consist of existing CS, so constraints that influence the requirements, architecture, or design could be extensive.

b) A system element is realized.

When SoS consist of existing CS, this outcome is achieved from the start, but only in part.

c) A system element is packaged or stored.

System elements can be necessary to facilitate interaction of the CS in the SoS. These are implemented by their owners who are responsible for maintaining and operating them.

d) Any enabling systems or services needed for implementation are available.

The remaining system elements need to be realized. These could relate to SoS information management and support infrastructure to enable other SoS to flourish and develop as needed. Time phasing of CS changes should be carefully planned to ensure that (a) each CS continues to support its independent capabilities, (b) the appropriate CS changes are in place at a given time to support the desired SoS capability, and (c) desired interactions and capabilities are not damaged by CS changes.
e) Traceability is established.

Outcome applies as stated to SoS.

6.4.9 Integration process

6.4.9.1 Purpose

The purpose of the Integration process in ISO/IEC/IEEE 15288:2015, 6.4.8 is shown in the box.

The purpose of the Integration process is to synthesize a set of system elements into a realized system (product or service) that satisfies system requirements, architecture, and design.

This process assembles the implemented system elements. Interfaces are identified and activated to enable interoperation of the system elements as intended. This process integrates the enabling systems with the system-of-interest to facilitate interoperation.

NOTE 1 For a given level of the system hierarchy, this process iteratively combines implemented system elements to form complete or partial system configurations in order to build a product or service. It is used recursively for successive levels of the system hierarchy.

NOTE 2 The interfaces are defined by the Architecture Definition and Design Definition processes. This process coordinates with these other processes and checks to make sure the interface definitions are adequate and that they take into account the integration needs.

The purpose of the Integration process in ISO/IEC/IEEE 15288:2015, 6.4.8 applies as stated to SoS.

6.4.9.2 Outcomes

The outcomes of the Integration process in ISO/IEC/IEEE 15288:2015, 6.4.8 apply as stated in the boxes with the following additions:

As a result of the successful implementation of the Integration process to an SoS:

a) Integration constraints that influence system requirements, architecture, or design, including interfaces, are identified.

SoS often consist of existing CS, so integration constraints that influence system requirements, architecture, or design, including interfaces, could be extensive. Integration for the SoS is sometimes performed in an operational environment.

CS often pre-exist the SoS and are already operating to provide their desired capabilities. Rather than building up the SoS from its components, SoS Integration takes the form of implementing new