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Systems and software engineering — System of systems (SoS) considerations in life cycle stages of a system

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Foreword

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

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ISO/IEC/IEEE 21839 was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 7, *Software and systems 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.

ISO/IEC/IEEE 21839 is one of three standards dealing with systems of systems. The relationship among the three standards is described in Annex C.

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.

Systems and software engineering — System of systems (SoS) considerations in life cycle stages of a system

1 Scope

1.1 Purpose

This document provides a set of critical system of systems (SoS) considerations to be addressed at key points in the life cycle of the system of interest (SoI). This document refers to considerations that apply to an SoI that is a constituent system that interacts in an SoS. The considerations and life cycle model align with those which are already defined in ISO/IEC/IEEE 15288 and ISO/IEC/IEEE 24748-1. Selected subsets of these considerations can be applied throughout the life of systems through the involvement of stakeholders. The ultimate goal is to achieve customer satisfaction, so that when delivered, the SoI will operate effectively in the operational or business environment which is typically characterized as one or more systems of systems.

This document concerns those systems that are man-made and are configured with one or more of the following: hardware, software, humans, procedures and facilities.

1.2 Field of application

This document addresses SoS considerations that apply to systems at each stage of their respective life cycles.

There is a wide variety of systems in terms of their purpose, domain of application, complexity, size, novelty, adaptability, quantities, locations, life spans and evolution. This document is concerned with describing the system of systems considerations that apply to a system that is the SoI; that is a constituent system within a system of systems. It applies to one-of-a-kind systems, mass produced systems or customized, adaptable systems.

1.3 Limitations

This document does not detail the approach to addressing system of systems considerations in terms of methods or procedures.

This document does not detail the described documentation in terms of name, format, explicit content and recording media of documentation.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC/IEEE 24765, *Systems and software engineering — Vocabulary*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions in ISO/IEC/IEEE 24765 and the following apply.

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 https://www.electropedia.org/

— IEEE Standards Dictionary Online: available at https://ieeexplore.ieee.org/xpls/dictionary.jsp

3.1.1
constituent system
independent system that forms part of a *system of systems (SoS)* (3.1.4)

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, utilization, goals, and resources, but interacts within the SoS to provide the unique capability of the SoS.

3.1.2
life cycle
evolution of a system, product, service, project or other human-made entity from conception through retirement

[SOURCE: ISO/IEC/IEEE 15288:2015, 4.1.23]

3.1.3
system of interest
SoI
system whose life cycle is under consideration in the context of this document

[SOURCE: ISO/IEC/IEEE 15288:2015, 4.1.48, modified — the abbreviated term "SoI" has been added; "this International Standard" has been replaced with "this document".]

3.1.4
system of systems
SoS
set of systems or system elements that interact to provide a unique capability that none of the *constituent systems* (3.1.1) can accomplish on its own

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

3.1.5
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 — "this International Standard" has been replaced with "this document".]

3.2 Abbreviated terms

SoI	system of interest
SoS	system of systems
SoSE	system of systems engineering

4 Concepts

4.1 System of systems

Both individual systems and SoS conform to the accepted definition of a system in that each consists of parts, relationships and a whole that is greater than the sum of the parts; however, although an SoS is a system, not all systems are SoS.

Maier (1998) postulated five key characteristics (not criteria) of SoS: operational independence of component systems, managerial independence of component systems, geographical distribution, emergent behavior and evolutionary development processes. Maier identified operational independence and managerial independence as the two principal distinguishing characteristics for applying the term "systems-of-systems". A system that does not exhibit these two characteristics is not considered a system-of-systems regardless of the complexity or geographic distribution of its components[5].

An essential characteristic is that each constituent system within the SoS is operationally independent. That is, each constituent system can operate independently to fulfil some number of purposes on its own.

In an SoS, systems are also managerially independent. That is, each constituent system is likely to be managed by organizations with a level of independence, with potentially different goals and objectives for the constituent systems.

In some cases, there may be a designated entity with some type of responsibility that spans an SoS. These managerial arrangements may be loosely defined or more highly structured depending on the particular situation. In other cases, no such entity may exist.

4.2 Constituent systems

An essential concept is that the system of systems is comprised of constituent systems (and may include other elements) that interact to provide capabilities that no one system or element in the SoS can provide by itself. Each constituent system is an independent system that provides capabilities to meet its specified mission or business objective and has its own life cycle, management and governance and technical requirements. Constituent systems include systems which are often considered as infrastructure, such as communications systems. A constituent system can be an entity in more than one SoS. An SoS is often comprised of existing constituent systems along with new constituent systems which are developed and integrated into the SoS. The focus of this document is a constituent system as the SoI, as is shown in Figure 1. The considerations provided in this document are with respect to what is necessary to account for the life cycle of the constituent system or SoI to enable it to interact in the anticipated SoS configurations.

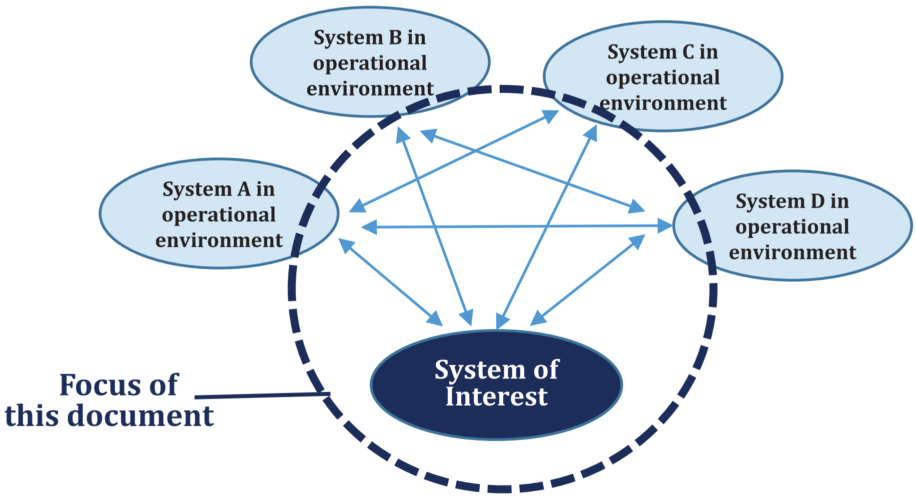


Figure 1 — Focus of the document is on the constituent system in an SoS

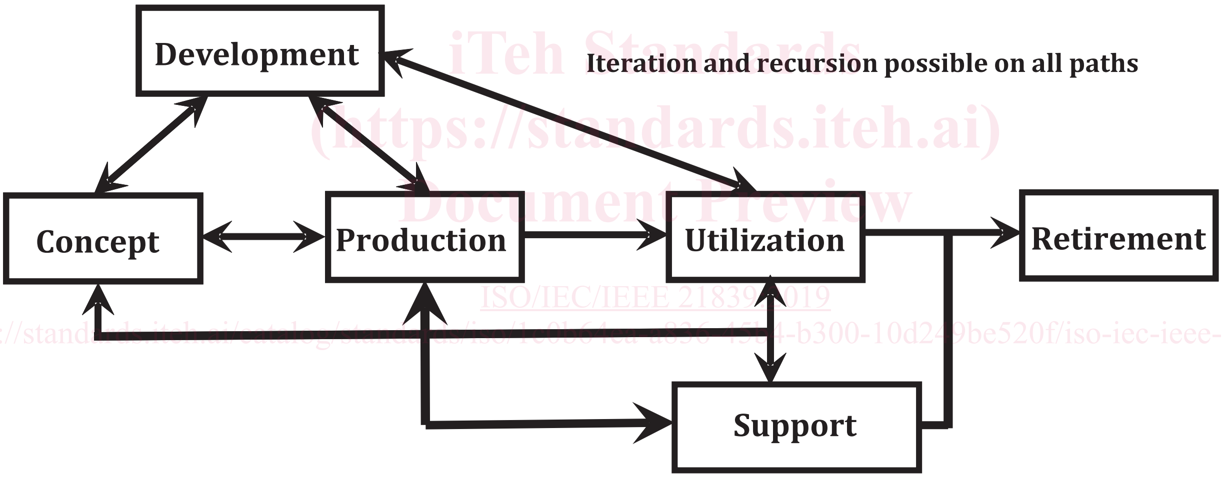
SoS and constituent systems can apply to any domain. For example, in an air transportation SoS, constituent systems may include the air traffic management systems, airports and aircraft. In a money transfer SoS (see an example in Annex B), constituent systems may include different banks. In a military SoS, weapons, sensors and communication systems may be considered constituent systems. This document addresses the SoS considerations for the life cycle stages of systems (new or evolving) which are constituents of one or more SoS.

4.3 System life cycle stages

As a system of systems evolves, each constituent system follows the representative life cycle stages for its own evolution. The representative life cycle stages are shown in Figure 2. These stages may be implemented in different progression with iteration and recursion possible, one example of which is shown in Figure 3. Table 1 summarizes the main purpose of each life cycle stage and shows decision options common across all life cycle stages.

NOTE See ISO/IEC/IEEE 24748-1:2018, Figure 6.

Figure 2 — Life cycle stages



NOTE See ISO/IEC/IEEE 24748-1:2018, Figure 7.

Figure 3 — Possible progress of life cycle stages

Table 1 — Life cycle stages, their purposes and decisions options

<table>
<tr><th>Life cycle stages</th><th>Purpose</th><th>Decision options</th></tr>
<tr><td>Concept</td><td>Identify stakeholders' needs
Explore concepts
Propose viable solutions</td><td rowspan="6">— Begin subsequent stage or stages
— Continue this stage
— Go to or restart a preceding stage
— Hold project activity
— Terminate project</td></tr>
<tr><td>Development</td><td>Refine system requirements
Create solution description
Build system
Verify and validate system</td></tr>
<tr><td>Production</td><td>Produce systems
Inspect and test</td></tr>
<tr><td>Utilization</td><td>Operate system to satisfy users' needs</td></tr>
<tr><td>Support</td><td>Provide sustained system capability</td></tr>
<tr><td>Retirement</td><td>Store, archive or dispose of system</td></tr>
<tr><td colspan="3">NOTE See ISO/IEC/IEEE 24748-1:2018, Table 1.</td></tr>
</table>

In this document, system of systems considerations are addressed at each of these stages for a system of interest that is intended to interact with other systems (a constituent system of an SoS) as shown in Figure 3. The stages are addressed as follows: Concept (5.1), Development (5.2), Production (5.3), Utilisation and Support (5.4) and Retirement (5.5).

As the focus of this document is the life cycle of the constituent system as the system of interest, SoS considerations to be addressed in each stage in the life cycle of a system are presented as a list of questions along with the supporting material. SoS considerations are grouped into three areas: Capability, Technical and Management (including schedule and cost). The document addresses both the benefit to the system of addressing these SoS questions and the risks of failing to address the questions. It identifies the type of information or artifacts that provide the information needed to address the questions and potential actions.

In this document, each stage presents three areas to consider:

— **Capability considerations**: In this document, capability refers to the ability to achieve overall user objectives in a mission or business context. User capabilities are often based on the collective effects of multiple physical systems (referred to as "material") as well as other factors beyond the systems themselves (training, procedures, etc. which are referred to in this document as "non-material"). Typically, the development of an SoI begins with a user need based on an identified gap in capability and a proposed SoI that focuses on filling that capability gap. From the earliest point in its life cycle, understanding the role of the SoI in supporting the needed capability is a key concern, particularly understanding: 1) how the SoI is envisaged to function in the operational or business context, 2) the constraints that context places on the SoI, and 3) the relationships, interfaces and dependencies between the SoI and other systems supporting the capability. Relevant ISO/IEC/IEEE 15288 processes are Business or Mission Analysis and Stakeholder Needs and Requirements Definition.

— **Technical considerations**: As alternative approaches to the SoI are evaluated, consider the technical impact on external stakeholders and external systems and infrastructure. This includes both systems/services on which the SoI depends and systems/services that depend on the SoI. Once these have been identified, assess the ability to influence resource changes in associated systems, infrastructure or nonmaterial factors. Consider any constraints on the SoI imposed by its SoS context in selecting the system solution. As the SoI life cycle moves into requirements definition and design, the technical considerations play a larger role. Understanding these early and factoring them into the technical planning process can be key to successful delivery of both the SoI and the capability it enables. Relevant ISO/IEC/IEEE 15288 processes are all the Technical processes.

— **Management considerations**: Consider management issues when dependencies resulting from interactions need to be negotiated with other systems involved (e.g., interfaces, new or changed functionality in other systems). If there is an entity with some type of responsibility that spans an SoS, establish management arrangements with that entity. SoS-related cost and schedule considerations need to be addressed, including identifying costs and schedules associated with external systems. Finally, mechanisms should be in place to monitor the progress in the areas of cross-system dependencies for a prompt identification of any changes or delays which could mean added cost and time. Plans need to be formulated to accommodate these if necessary. Relevant ISO/IEC/IEEE 15288 processes are all the Technical Management processes and all the Agreement processes.

In this document, certain considerations need to be addressed at multiple stages, so if a question also applies to more than one stage, this is noted.

A system may interact as part of one or more SoS in support of multiple capabilities. In this document, when the interaction of a system with an SoS is discussed, this may include one or more SoS in support of one or more capabilities. Thus, although the terms SoS, capability and context are used in singular form throughout this document, each use can be plural if applicable to the situation.

4.4 SoS technical base

Annex A presents what is termed the "SoS technical base", which reflects the type of SoS level technical information that would ideally be available as a reference to an SoI in addressing wider SoS considerations. As is shown in Figure 1, this document applies to a constituent SoI in an SoS. The SoS technical base information in Annex A may be available to provide reference information used to address the SoS considerations and help ensure that organizations responsible for constituent systems in the SoS can address these considerations in a consistent manner and reduce risks at both the system and the SoS levels. It is recognized that in many cases, this information may not be available, putting an added burden on the SoI to address the SoS considerations across the multiple organizations.

5 System of systems considerations in SoI life cycle stages

5.1 SoS considerations in the Concept Stage

5.1.1 General

This subclause describes the SoS considerations for the SoI to be addressed in the Concept Stage as defined in ISO/IEC/IEEE 24748-1:2018, 5.2. Details of the Concept Stage from ISO/IEC/IEEE 24748-1 are shown in Box 1.

5.1.2 Concept stage capability considerations

Upon entry into the Concept Stage, evaluate all available information that is relevant to help understand the user capability needs and identify information gaps. In particular, address questions concerning the understanding of the capability being sought, and the context of that user capability need, including, but not limited to:

— Has the operational or business context of the user capability need been described?

— Has the existing user capability been described, including the systems or SoS that currently support that capability?

— How would a new system which might address the gap fit into current operations or business processes?

— If a new system were to be considered, have interfaces with or required changes to current systems or systems which are planned or in development been identified?

Identifying and addressing constraints are key to effective solutions. An early description of the SoS context and its potential impact on requirements and dependencies for the SoI provide a solid basis for the development of a system that can meet user needs, including quality characteristics.

Potential changes to other systems, interfaces and infrastructure need to be identified as early as possible. This will allow time for multi-lateral SoS trade-off analyses, considering which changes should be implemented or where they can best be implemented and allow time for negotiations and organizational agreements to be put in place. Early identification of dependencies between developing or planned systems provides the opportunity to help ensure that interoperability is maintained despite changes. An early understanding of these factors can contribute to a sound solution selection for the SoI and an assessment of SoS risks. This is particularly important for any long-lead items.

Understanding of current operations, business processes and life cycle support is also important to set the context for the SoI. This includes systems currently supporting the SoS capability, systems in development or planned and any non-material elements. Consider the full impact of alternatives in the assessment of possible approaches for addressing the gap(s), including any required changes to operations, business processes or life cycle support to avoid unwanted effects on other capabilities.

During the Concept Stage, there is a set of questions concerning the capability being sought and the context of that need. These questions build on any capability considerations addressed previously and address the implications at the next level of detail.

Box 1 Concept Stage

(From ISO/IEC/IEEE 24748-1:2018)

Concept Stage (5.2)

Overview (5.2.1)

The Concept Stage begins with initial recognition of a need or a requirement for a new system-of-interest or for the modification to an existing system-of-interest. This is an initial exploration, fact finding, and planning period when economic, technical, strategic, and market bases are assessed through acquirer/market survey, business or mission analysis, solution space identification and feasibility analysis and trade-off studies. Acquirer/user feedback to the concept is obtained.

One or more alternative concepts to meet the identified need or requirement are developed through analysis, feasibility evaluations, estimations (such as cost, schedule, market intelligence and logistics), trade-off studies, and experimental or prototype development and demonstration. The need for one or more enabling systems for development, production, utilization, support and retirement of the system-of-interest is identified and candidate solutions are included in the evaluation of alternatives in order to arrive at a balanced, life cycle solution. Typical outputs are stakeholder requirements, concepts of operation, assessment of feasibility, preliminary system requirements, outline architecture and design solutions in the form of drawings, models, prototypes, etc., and concept plans for enabling systems, including whole life cost and human resource requirements estimates and preliminary project schedules. Decisions are made whether to continue with the implementation of a solution in the Development Stage or to cancel further work.

It is presumed that the organization has available enabling systems for the Concept Stage that consist of the methods, techniques, tools and competent human resources to undertake market/economic analysis and forecasting or mission analysis, feasibility analysis, trade-off analysis, technical analysis, whole life cost estimation, modelling, simulation, and prototyping.

Purpose (5.2.2)

The Concept Stage is executed to assess new business opportunities or mission assignments and to develop preliminary system requirements and a feasible architecture and design solution.

Outcomes (5.2.3)

The outcomes of the Concept Stage are listed below.

a) Plans and exit criteria for the Concept Stage;

b) The identification of new concepts that offer such things as new capabilities, enhanced overall performance, or reduced stakeholders' total ownership costs over the system life cycle;

c) An assessment of feasible system-of-interest concepts, with initial architectural and other solutions, including enabling systems throughout the life cycle, for closure against both technical and business or mission stakeholder objectives;

d) The preparation and baselining of stakeholder requirements and preliminary system requirements (technical specifications for he selected system-of-interest and usability specifications for the envisaged human-machine interaction);

e) Refinement of the outcomes and cost estimates for stages of the system life cycle model;

f) Risk identification, assessment and mitigation plans for this and subsequent stages of system life cycle model;

g) Identification and initial specification of the services needed from enabling systems throughout the life of the system;

h) Concepts for execution of all succeeding stages;

i) Definition of the enabling system services required in subsequent stages;

j) Plans and exit criteria for the Development Stage;

k) Satisfaction of stage exit criteria;

l) Approval to proceed to the appropriate stage or stages, based on the specific life cycle model in use by the project.

— Is the SoS context (or multiple SoS contexts) given in an up-to-date description of how the users will conduct the operation or business process and how they expect to use the new system?

— Have operational or business context constraints on potential solutions been identified? (E.g., business or operational continuity needs based on the importance of the capability being continuously available.)

— How would the SoI fit into current and future operations?

— Have the relationships between the SoI and other constituent systems been communicated?

— Have interfaces with or required changes to systems in development or planned systems been identified?

— Have the benefits from and for other systems been identified? Have these been communicated to these systems?

— Have impacts on non-material factors (e.g., personnel, training, description of how the users will conduct the operation or business process, life cycles support, other) been described?

If there is no description of how users expect to use the new SoI that is coordinated with the overall description of how the users will conduct operations in an SoS context or environment, the risk is that