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

Ingénierie du logiciel et des systèmes — Études du système des systèmes (SdS) dans les étapes du cycle de vie d'un système

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Foreword

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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.

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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.

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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

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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.

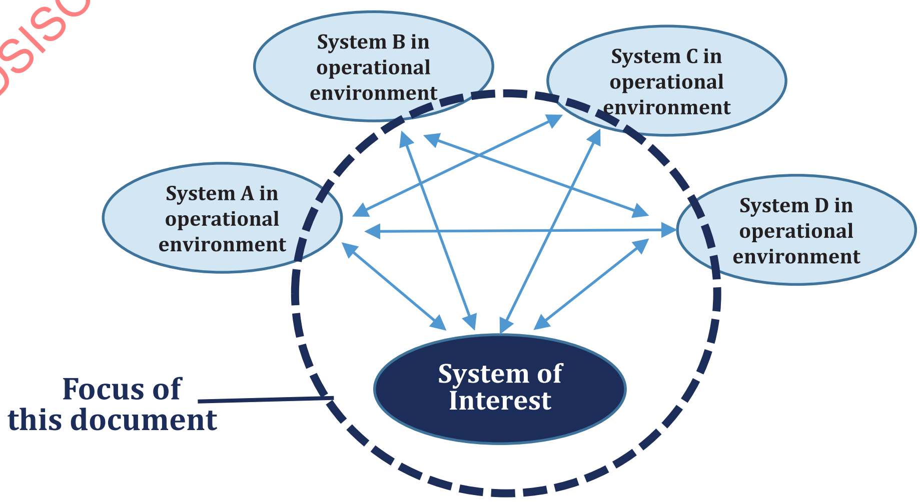

Figure 1 — Focus of the document is on the constituent system in an SoS

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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.

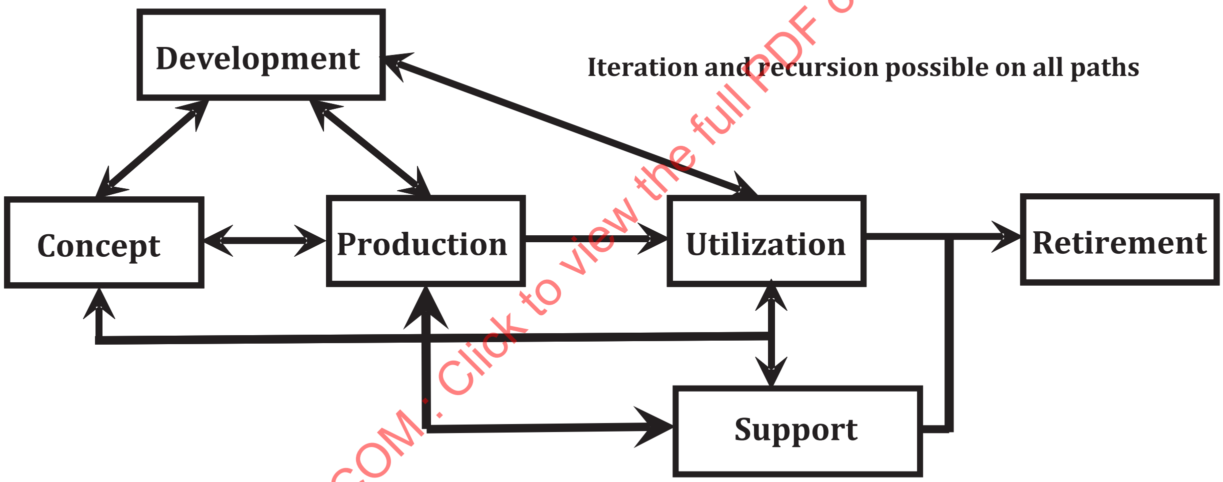
4.3 System life cycle stages

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.

Concept	**Development**	**Production**	**Utilization**	**Support**	**Retirement**

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

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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

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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?

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— 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.

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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.

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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

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requirements and dependencies may be missed. This can lead to an ineffective SoI when placed in an SoS context or environment, unexpected higher costs or schedule slippage due to necessary rework.

Expected here is a written description, which contains a delineation of how the SoI will work in the context of other systems and in the operational or business context, which is consistent with the view presented in the description of how the users will conduct SoS operations. The context will also need to describe how the new SoI is expected to be used with other systems to address the user's capability objectives. If the written description has not been completed, priority should be given to developing and validating how users expect to use the new system, which identifies key elements external to the proposed system, including those that would support the SoI through its life cycle, and their impact on system attributes and functionality — as well as impacts of the SoI on these external factors — to help ensure compatibility with existing descriptions of how the users will conduct operations overall.

Considering non-material factors early provides sufficient lead-time to address cross-organizational enablers such as resources, organizational impact, training, life cycle support, personnel multi-role postings and recruitment focus. Considering impacts or factors from the SoS or its constituent systems helps to avoid the risk that the solution considered or selected will fail to achieve the desired capabilities, incur added, unexpected costs or schedule slips, or result in unwanted, negative effects on other capabilities.

— How does the proposed SoI help to address the capability gap in the context of the SoS?

A description of how the proposed SoI addresses the capability gap, in the context of the systems currently supporting the capability, will provide the basis for understanding key attributes of the SoI and key relationships to be considered in SoI requirements. Defining the linkage between the proposed SoI and the other systems supporting the capability helps to avoid the risk that the system may fail to meet user objectives. At this stage, there should be results of analysis, simulation, prototyping or experimentation to support an assessment of consistency or change from the previous stage. If this has not been addressed, using data from simulations, prototypes or live events, analysis should be conducted on the end-to-end actions based on the description of how the users will conduct operations, to verify that the SoI will support the capability need in the context of the SoS currently supporting the capability.

— Have roles of the SoI in different missions or activity threads been identified and prioritized?

A description of the variety of roles that a system will play, including any concurrent roles in multiple SoS, will provide a strong foundation for system requirements. If a system has roles in several missions, early identification of the capability development information requirements will help to ensure availability of that information and will help to avoid the risk that the system will fail to meet all user objectives. By this point there should be identification of mission or SoS interfaces, information suppliers, protocols, standards responsibilities and interoperability requirements. If this has not yet been addressed, the interoperability requirements and driving interfaces should be identified or developed in the order of priority within resource constraints, along with the applicable protocols and standards.

— How critical are the interoperability requirements to the interdependencies?

Understanding the criticality of SoS interoperability will provide a basis for understanding the impact of any future trade-offs. Identifying the relative importance of interoperability requirements helps to avoid the risk that the wrong things may be traded away. If this has not yet been addressed, develop and validate a "criticality analysis" with stakeholders to understand the criticality and priority of various interdependent functions.

5.1.3 Concept Stage technical considerations

Upon entry to the Concept Stage the following technical questions should be addressed:

— Have the external stakeholders and systems affected been identified? This includes both systems and services on which the new or upgraded system depends and systems or services that depend on the new or upgraded system.

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— Is there an understanding of the ability to influence changes in associated systems or non-material factors?

Early identification (upon entry into Concept Stage) of key external parties impacted by the new system (SoI) and their ability or willingness to affect and provide the resources for the needed changes will provide a realistic planning basis for the system development, including identification of any potential or current shared developmental costs and tools. Describing the systems context helps to avoid the risk that the selected solution may be infeasible due to needs of stakeholders of affected systems or an inability to adjust associated systems to address capability gaps.

At this stage, there should be lists of external stakeholders and of dependent systems and their proponents and resource sponsors, including maintainers for in-service systems available along with an early list of assumptions and dependencies. If this has not been done by this stage, it would be important to explicitly identify and contact potentially affected stakeholders to avoid risks identified above.

Several technical considerations should be addressed during this stage:

— What are the key drivers for the implementation of the SoI (cost, schedule, performance) that may be guided by SoS related issues?

— What are the key trade-off factors for the SoI within the larger SoS that may influence constraints, coherence (including reuse and evolution considerations), systems attributes, interfaces or other design considerations for the system?

— Has the analysis been undertaken to resolve these SoS issues, and if not, how can they be resolved to guide the implementation of this system?

— What constraints on the SoI are imposed by the SoS context for the system?

— Have these been considered in selecting the SoI solution?

Identifying the SoS drivers and constraints and top-level trade-off factors early in the Concept Stage helps define the work to be done to help inform the selection of the preferred system approach (e.g. the critical parameters that may need to be modelled) and provides the basis for considerations that affect the selection of the preferred system approach. These drivers and constraints may include: physical requirements (e.g., size, weight, cooling, power limits), electronic requirements (e.g., signature, interference, etc.), information exchange and management (e.g., network, bandwidth, information needs, etc.), safety, system assurance (e.g., security, information assurance, system integrity), and reliability and availability (e.g., to maintain business and operational continuity).

Identifying drivers, trade-off factors and constraints is key to developing effective solutions. Understanding these early can contribute to the selection of a sound and feasible solution. Recognizing the SoS drivers and constraints and resulting requirements helps to avoid the risk that the resulting SoI may fail to operate as expected or meet the needs of the SoS environment or may incur unexpected additional time or budget for rework. This also needs to consider if the SoS meets its stakeholder needs, as it could operate as expected, but fail to meet the needs. Results of early engineering analyses would highlight the impacts on the solutions; ideally these impacts would have been addressed in the analysis of solution options and are considered in the selected solution, helping to mitigate the risks. If this has not been addressed, document the drivers and constraints of the SoS context on alternative system solutions and the way the selected system solution addresses these constraints.

— What are the dependencies and interfaces for the system?

Describe how the system dependencies and interfaces have been identified and are defined and controlled. Additional questions include how tightly coupled are the interdependent systems and how will the interfaces be managed across the different systems? Dependencies can be key to an SoI to success in meeting user needs, so identifying these early in the life cycle provides a sound basis for the selection of the most appropriate solution. Identifying the dependencies and interfaces when assessing alternatives or identifying preferred options helps to avoid the risk that the resulting system fails to address these dependencies in the system requirements or the system design, etc., and hence the SoI may fail to perform as needed in the intended SoS environment.

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During this stage, there should be a representation of the SoS architecture with the identification of interfaces and dependencies to the solution options and inclusion of these in the analysis of options and in the definition of the preferred solution. If the representation has not been addressed, utilize the description of how the users may conduct the end-to-end set of actions supporting the user capability as well as a representation of the SoS architecture. This description can be employed to define the role of the proposed SoI with respect to other systems, in terms of interfaces (see the item above) and other physical and logical functions. These factors should be included in the assessment of system options.

— Are there any other systems critical to the success of the proposed SoI? Who is responsible for these systems and do they acknowledge the dependency?

— Are there impacts on these systems that need to be addressed to meet the capability needs once the new system or system upgrade is implemented?

Identifying where other systems are key to the SoS success and making early contact with their management can provide the basis for successful collaboration throughout the development. Addressing expectations of other systems (things they need to change or things they need to continue to do) helps to avoid the risk that the selected solution option alone will be insufficient to meet user needs. At this stage, identification of the external systems and recognition of their roles in the mission should be defined. If this identification has not been addressed, develop a functional allocation across systems to allow the identification of external dependencies to be addressed during the selection of the preferred solution.

5.1.4 Concept Stage management considerations

If there exists an entity with some type of responsibility that spans systems that are key to the SoS success, then critical questions to ask, include, but are not limited to:

— What entity (if any) is responsible for each SoS in which the SoI is intended to interact?

— What management arrangement has been established between the SoI and the SoS?

— Have these been formalized? Do these arrangements address schedule and resources, including budget?

— Have these arrangements been implemented?

Identifying and working with an established SoS level entity as early as possible in a system life cycle can provide the SoI team with ready access to key information and existing arrangements to help ensure the system planning and development is aligned with the larger SoS. The type of information which would ideally be available from an SoS technical base is shown in Annex A.

If the role of the proposed system is not understood in the context of the SoS, as the SoI matures, the risk is that the SoI may be incompatible with or operationally unsuitable for the current and future direction of the SoS or it may incur added costs and time for necessary rework. In addition, where there may be competing requirements, an approach to determine how conflicts will be mitigated is beneficial.

Management agreements should be established with the SoS and a cooperative action plan developed which addresses how both management entities will work together over time (throughout the life cycle) to enable coherent SoI requirements, implementation, test, etc. If this has not been addressed, then work with the entity responsible for the SoS to help ensure that plans for the SoI and SoS are aligned. This should include consideration of the software and hardware life cycles of other constituent systems within the SoS. These working arrangements should be revisited as needed to assure continued alignment with the SoS and its constituent systems.

If there is no entity with some type of responsibility which spans the SoS, then several other questions should be addressed.

— What management arrangements have been made with other systems which impact the SoI (including when a system participates in multiple SoS)?

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— Have these arrangements been implemented?

Establishing arrangements with other systems early can provide a key foundation of collaborative efforts throughout the full system life cycle. This includes both enabling systems as well as systems which will be present when the SoI is fielded. If the role of the SoI is understood in the context of an SoS, as the SoI matures, this avoids the risk that the SoI will be incompatible with the current and future direction of the SoS and will be operationally unsuitable or incur added costs and time for necessary rework. Plans for the SoI need to consider the willingness or ability of other key systems to share information and arrangements to support SoS objectives and requirements. SoI owners need to recognize potential negative consequences or costs associated with non-participation in an SoS and find approaches to work cooperatively with the other systems in the SoS.

Management arrangements need to be established with the relevant systems and a cooperative action plan produced which includes how the systems will work together over time (throughout the life cycle). The cooperative action plan will support the development of system requirements, implementation, test, etc., for the system of interest. If this has not been addressed, engage with the managers or systems engineers of the relevant systems to help ensure that plans for the SoI align with those of the other relevant systems.

5.2 Addressing SoS considerations in the development stage

5.2.1 General

This subclause describes the SoS considerations to be addressed in the Development Stage as defined in ISO/IEC/IEEE 24748-1:2018, 5.3, see Box 2.

5.2.2 Development stage capability considerations

At this stage verify that there is a current understanding of the capability being sought and the context of that capability need, as it may have changed, and the changes could impact the development.

— Is the SoS context (or contexts) defined in the updated operational concept along with a description of how the users expect to use the SoI in this context?

— Are there any changes to the operational context constraints that impact the system?

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

— How does the proposed SoI help to address the capability gap in the context of the SoS?

— Have the relationships with other constituent systems supporting the SoS capability changed?

— Are the expected changes to other constituent systems being progressed as expected, or are there issues that may impact the SoI?

— Is there continued focus that the system solution is addressing the SoS capability gaps in the in the end-to-end SoS capability?

As has been stated under other stages, an understanding of the SoI's context and its potential impact on system requirements and dependencies will provide a solid basis for the development of an SoI which will meet user needs. During the Development Stage, understand the operational concept and how the users expect to employ the SoI within the SoS context. This needs to be supported by the requirements and system design. Attention to this during the Development Stage helps to avoid the risk that requirements and dependencies may be missed or traded away, leading to an ineffective system or unexpected higher costs if changes are needed later in the development or deployment to correct the deficiency. To guide the development, there should be an up-to-date documented description of the operational concept with a delineation of how the SoI will work within the context of other systems and

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the operational context. If this has not been addressed, it is critical at this point to develop and validate the description of how the SoI users will conduct the operation with SoS users.

— Have the roles of the SoI in different SoS been identified and prioritized?

As may have been considered in other stages, understanding the variety of roles that a system will play will provide a strong foundation for system requirements. If an SoI has roles in several SoS and if the capability development information and associated requirements are not identified, the risk is that the SoI will not meet the full set of user objectives. At this point, there should be an identification of the owners of SoS interfaces and their responsibilities. If this has not been addressed, action is needed to develop interoperability requirements and identify technical parties who will address both the management and the approval of changes to applicable protocols. Interoperability requirements should be identified or developed in the order of priority within resource constraints and driving interfaces along with protocols and standards should be identified.

— How critical are the interoperability requirements to the interdependencies (sensitivity considerations)? Has this changed?

— Are user expectations and implementation aspects for interoperability of the SoI clearly captured?

— Are there any implementation issues that would impact how the SoI would support current and future operations?

— Are the respective development responsibilities for interfaces affecting the SoI established and understood?

— Have interfaces of the SoI with respect to the SoS been developed/implemented as expected?

The question may have already been addressed but should be revisited during the Development Stage since understanding the relative criticality of interoperability requirements can impact design trade-offs. A criticality analysis of requirements and priorities should be available at this stage, and if not, develop and validate with stakeholders an understanding of the criticality and priority of various interdependent functions.

Box 2 Development Stage

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

Development stage (5.3)

Overview (5.3.1)

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The Development Stage begins with sufficiently detailed technical refinement of the system requirements, system architecture, and the design solution, and transforms these into one or more feasible products that enable a service during the Utilization Stage. The system-of-interest may be a prototype in this stage. The hardware, software, operator, process, and facility interfaces are specified, analysed, designed, fabricated, integrated, tested and evaluated, as applicable, and the requirements for production, training, and support facilities, and transitions, are defined. This stage also involves considering and incorporating into the design the applicable constraints of other stages (production, utilization, support, and retirement) and their enabling systems' requirements and capabilities. Feedback is obtained from stakeholders and those who will produce, operate, use, support, and retire the system-of-interest through such means as a series of technical or other reviews. Outputs are a system-of-interest or a prototype of the final system-of-interest, refined requirements for enabling systems or the enabling systems themselves and all documentation and cost estimates of future stages.

Planning for this stage includes preparing to establish an infrastructure of development enabling systems, consisting of facilities, processes, procedures, methods, techniques, tools and competent human resources to undertake analysis, modelling and simulation, prototyping, design, integration, test, transition and documentation. These items are developed or acquired to be available when needed to support development.

Purpose (5.3.2)

The Development Stage is executed to develop a system-of-interest that meets stakeholder requirements and can be produced, tested, evaluated, operated, supported and retired.

Outcomes (5.3.3)

The outcomes of the Development Stage are listed below.

a) Plans and exit criteria for the Development Stage.

b) Architectural and design artefacts for the system of interest.

c) A system-of-interest structure comprised of, for example, hardware elements, software elements, human elements, process elements, facility elements and the interfaces (internal and external) of all such elements.

d) Verification and validation documentation.

e) Transition planning documentation.

f) Evidence supporting a decision, with all risks and benefits considered, that the system-of-interest meets all specified requirements and is producible, operable, supportable and capable of retirement and is cost-effective for stakeholders.

g) Refined and baselined requirements for the enabling systems, along with methods and tools for establishing and maintaining traceability between requirements and the developed system.

h) A prototype or final system-of-interest.

i) Refined outcomes and cost estimates for the Production, Utilization, Support and Retirement Stages.

j) Identification of current risks and determination of their treatment.

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.

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5.2.3 Development stage technical considerations

There are many technical considerations to be addressed at this stage:

— What analysis has been done of the SoI in the context of the larger SoS to identify constraints, coherence (including reuse and evolution considerations), systems attributes, interfaces, performance requirements or other design considerations for the SoI? How have these been documented? How have these been captured in the system requirements?

Identifying and documenting the externally-imposed considerations into system requirements helps to ensure that they can be considered in the system design. Conducting an explicit analysis of the impact of external factors on systems helps to avoid the risk that these may not be identified, documented and reflected in system requirements and as a result the system may fail to address them and, when delivered, it may be operationally unsuitable or fail to support the user capability needs which motivated its development. Upon entry into the Development Stage, there should be documentation and traceability of SoI requirements to factors associated with the system context, validated by the right stakeholders representing external systems or factors. If this has not been done, use the operational concept as well as a representation of the SoS architecture to assess how the key elements of the context will impact the system and should be addressed as considerations in the system design and in the system requirements.

— Are user expectations for interoperability captured in system requirements?

— How are constraints on the SoI imposed by each SoS context addressed in the design?

— How are SoS technical requirements and resulting interfaces addressed in the SoI system design? Have mechanisms to monitor interfaces and other SoS impacts on the SoI been considered in the requirements and design?

The same set of constraints identified in other stages is now revisited with a specific focus on the SoI system design. As may have been noted earlier, these include: physical requirements (e.g., size, weight, cooling, power limits), electronic requirements (e.g., signature, interference, etc.), information exchange and management (e.g., network, bandwidth, information needs, etc.), safety, system assurance (e.g., security, information assurance, system integrity), reliability and availability (e.g., to maintain business and operational continuity) and protocols and standards. If there is an entity with some type of responsibility which spans the SoS (see management considerations below), the requirements on the system of that SoS (see Annex A) need to be considered as do the implied requirements if there is no such entity.

Constraints are key to effective solutions. Addressing these constraints can contribute to a sound system design. Addressing the SoS constraints and resulting requirements in the SoI system design helps to avoid the risk that the resulting system will not operate in the user environment or incur unexpected additional time or budget for rework. Results of early engineering analysis should highlight the constraints placed on the solutions and in the best case these constraints are addressed in the analysis of solution options and are reflected in the selected solution. It is equally important that the constraints placed on the solutions are adequately addressed in the design of the SoI. There should be documentation of the system requirements driven by the SoS context and traceability to the SoI system design. If this has not yet been addressed, modelling and simulation offer ways to understand how the SoS might perform and hence to explore the effect of possible choices as part of system development.

— What are the dependencies and interfaces for the SoI?

This includes both dependencies from a development perspective as well as operational dependencies. These may have already been identified but before entering the Development Stage, define how system dependencies and interfaces are identified, defined and controlled. Dependencies can be key to the SoI 's success in meeting user needs, so understanding the needs early in the life cycle can provide a sound basis for solution selection. Identifying the dependencies and interfaces when assessing system alternatives or identifying preferred options helps to avoid the risk that the resulting SoI may fail to factor these into requirements, design, etc., and hence may fail to perform or function as needed in the operational environment. A representation of the SoS architecture with the identification of interfaces

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and dependencies should be available at this point. If not, use the operational concept as well as a representation of the SoS architecture to define the role of the system with respect to other systems, in terms of interfaces and other physical and logical functions and include these as factors in planning for system development.

— Are there any (complementary) systems critical to the success of the SoI? Who is responsible for these systems and do they acknowledge the dependency?

— Have the appropriate system interfaces or changes been agreed?

— Are there impacts on these systems that need to be addressed to meet the capability needs once the new SoI or SoI upgrade is implemented? How are these addressed?

— Is the development of the SoI dependent on changes in associated systems, infrastructure, or non-material factors? If so, are risk mitigations in place?

Identifying where other systems are key to an SoI's success and establishing commitments for cooperation prior to the Development Stage can provide the basis for successful collaboration throughout development. If the expectations of other systems (things they need to change or things they need to continue to do) are not understood and considered, the risk is that the selected solution option alone will be insufficient to meet user needs. By this point there should be a description of how the users will conduct the operation and how the SoI will be used in this context and architecture along with the role of external systems to the achievement of the capability or mission objectives and recognition by the owners of the external systems of their parts of their role in the mission. This type of information would ideally be available from an SoS technical base as is shown in Annex A. If this has not been addressed, develop a functional allocation across systems for the preferred solution, both to allow the identification of external dependencies to be addressed as part of the selection of the preferred solution and to engage the owners of external systems.

— For considerations which involve interactions with other systems (e.g., interfaces, new or changed functionality in other systems), how are the design features negotiated with the others involved?

— Are there internal interfaces which may need to be exposed in the future to support evolving SoS needs?

If aspects of an SoI which are directly related to other systems are addressed early with the related parties, the design is more likely to be robust and meet user needs. A key area of engagement with external systems is the design of interfaces with those systems as well as any design for functionality changes or enhancements which are key to the new systems meeting the end-to-end user capability needs. If these design elements are not reviewed and supported by all the systems involved, the risk is that the system will fail to meet user capability needs. By this stage, there should be interface and functional designs agreed to by all players involved, supported by agreements, engagement plans and configuration management plans. If this has not been addressed, engage with managers and systems engineers of the relevant systems to plan for a coordinated review of designs as well as development and test of interfaces and cross system functionality in the system development plan and specify standards-based interfaces wherever possible.

— When technical trade-offs need to be made for the SoI, how are the impacts on the SoS or system coherence with the broader SoS considered?

Ensuring impacts on the capability and SoS are considered in trade-offs will reduce the risk that capability effectiveness is unintentionally lost in the design trade-off process. As development and detailed design proceeds, inevitably issues will arise and changes in requirements and design may need to be made. If these changes impact the way the SoI will work with other systems and the impact of the change on these other systems is not considered, the risk is that the resulting SoI may not work as intended and may not meet user needs without rework resulting in unanticipated additional budget and schedule. Plans should be in place with the dependent and related systems to review the design and development work at key points to identify any changes and resolve any issues. If this has not yet been

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addressed, develop an ongoing working relationship with dependent and related systems with planned regular interactions throughout development.

— How are SoS-derived technical requirements used in technical planning?

If there is a defined approach to addressing these external considerations in the SoI technical plans, they can most effectively be addressed as an integral part of the system engineering process. Considering these external factors early in the development process, working in conjunction with the owners of the external systems or areas, helps to avoid the risk that the SoI requirements will not capture their impact and the SoI will fail to meet user needs resulting in the need for rework. Technical plans include explicit arrangements to address these derived requirements supported by agreements and engagement plans, which can help to avoid future rework. If this has not been addressed, review the SoI systems engineering plans to identify ways these plans can be adjusted so they explicitly address the SoS-derived technical requirements, particularly in terms of agreements with external organizations' technical plans for the implementation of the agreements.

Success of any system is the ability to work in the end-to-end capability and to monitor the effect of the SoS on the system itself. By this point there should be an interface design and implementation plans agreed to by all players involved supported by formal agreements and engagement plans. If this has not been addressed, conduct an analysis of the end-to-end system of systems flow in supporting the user capability to provide the basis for identifying how the SoI fits into the larger SoS and the impacts on the SoI and other systems to effectively support the capability. It is also important to include the interfacing systems in the interface design review.

— How are SoS-derived technical requirements used to define interfaces and data sharing agreements?

If the derived technical requirements are directly tied to interface definitions these will be addressed as a part of the system development process. Key elements of any system requirements are the requirements associated with how that system fits into an end-to-end capability. If this is not considered in developing requirements for the SoI, the risk is that it may fail to meet user needs or incur unexpected time and budget to make changes to meet these needs. By this point there should be interface definitions and implementation plans agreed to by all players involved and supported by formal agreements, charter or data sharing agreements and engagement plans. If this has not yet been addressed, review requirements to ensure that they adequately address the key system interfaces and interdependencies.

5.2.4 Development stage management considerations

Most of the same management, cost and schedule considerations raised for the previous stage apply here as well, with one added consideration addressing the monitoring of costs and schedules. At this stage, there is more emphasis on the management of the technical design and interfaces, to assure alignment particularly if changes have taken place.

If there is an entity with some type of responsibility which spans the SoS, it is critical to ask

— What entity (if any) is responsible for the SoS which this system supports?

— What management arrangement has been established between the SoI and the SoS?

— Have these been formalized? Do these arrangements address the schedule and budget?

— Have these arrangements been implemented?

As considered in other stages, identifying and working with an established SoS level entity right from the start can provide the SoI development team with a ready access to key information and existing arrangements to help ensure the system development is aligned with the larger SoS. The type of information which would ideally be available from an SoS technical base is shown in Annex A.

If the role of the SoI is not understood in the context of the SoS, as the SoI is developed, the risk is that the SoI may not be compatible with or operationally support the current and future direction of the SoS or it may incur added costs and time for necessary rework. In the Development Stage,

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management arrangements should be established with the SoS, and a cooperative action plan should be developed including how the SoI and SoS owners will work together throughout the life cycle including sustainment. If this has not been addressed, arrange to work with the organizations responsible for the SoS to help ensure that plans for the SoI and SoS are aligned, including consideration of the software and hardware life cycles of other systems within the SoS. This should be revisited as needed throughout the development and production stages to assure continued alignment.

If there is no entity with some type of responsibility which spans the SoS, then

— What management arrangements have been made with other systems which impact this system (including when a system participates in multiple SoS)?

— Have these arrangements been implemented?

Establishing and implementing arrangements with other systems during the Development Stage can provide the basis for effective collaborative efforts throughout the system development. If the role of the proposed system solution is not understood in the context of an SoS, as the SoI develops, the risk is that the system solution will be incompatible with the current and future direction of the SoS and will be operationally unsuitable or incur added costs and time for necessary rework. Management arrangements should be established with the relevant systems and cooperative action plans should be in place with owners of the key systems in the SoS to support the coordination and tracking of system requirements, implementation, test, support, etc. If this has not been addressed, engage with the owners of the relevant systems to help ensure that plans for the system in question align with those of the other relevant systems and that there is a plan to track these throughout the Development Stage.

— Have the SoS-related systems costs, including integration costs, been identified and included in cost estimates, and is there a plan to track these as part of development?

— Have costs associated with external systems, including integration, been identified and included in cost estimates for these external systems? Does this include costs to upgrade, planning costs and costs of integration and test? Is there a plan to monitor these through the Development Stage?

This is an important consideration prior to entry into the Development Stage and should be tracked during the development. This includes costs of added requirements not identified when system costing was initially estimated (e.g., costs to integrate a new system onto a platform). If full costs of the system, including the SoS-derived costs, are planned for upfront and tracked throughout development, adequate resources are more likely to be available to meet development needs. If costs of SoS-related requirements are not included in cost estimates (and budgets), the risk is that these requirements will not be addressed and the actual costs for the system will be higher than expected.

If changes are needed in other systems, planning for these resources will help ensure that these changes will be implemented. This is a consideration for entry into the Development Stage and should be tracked during development. Including costs associated with external systems (including the time for these systems to work on planning) in the cost estimate (and budgets), helps to avoid the risk that these requirements will not be included in planning and needed development will not be implemented. Costs related to external systems should be reflected in cost drivers, cost and budget estimates. If this has not been addressed, during the Development Stage, engage with the owners of the relevant systems, to help ensure that plans for the system in question align with those of the other relevant systems and that funding has been planned and is being tracked.

— Have schedules for the development of relevant systems been identified and included in plans?

This includes the sequence of events and associated dependencies. If the full schedule for a new SoI is planned upfront, including all the associated activities potentially affecting it, adequate time is more likely to be available to meet development needs. Accommodating schedules of SoS-related modifications in the SoI plans helps to avoid the risk that the schedule requirements will not be addressed or the actual costs for the SoI will be higher than expected. Schedules related to external systems should be reflected in the SoI schedules and budget estimates. If this has not been addressed, engage with the

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managers or systems engineers of the relevant systems, to help ensure that plans for the SoI align with those of the other relevant systems, particularly the schedules of elements of shared interest.

— Have mechanisms been implemented to monitor the progress in the areas of cross-system schedule dependencies for the early identification of changes or delays which could mean added costs?

— Is it clear who is responsible for doing the monitoring?

— Have plans been formulated to address risks and impacts to the system and the SoS if schedules shift?

— Have plans been formulated to accommodate additional costs, if necessary?

If a monitoring process is put into place, when inevitable changes occur, they can be quickly identified and addressed. If there is no plan in place for monitoring the progress related to external systems' schedules and cost, the risk is that this area is likely to be neglected and that there will be unexpected technical or testing issues adding to the cost and schedule. Implementation or oversight plans should explicitly track the execution of external engagement activities, with milestones (interface specification, development, test, etc.), to identify risks and issues early along with plans for how to address the impacts of these shifts. If this has not been addressed, it is important to engage with the managers or systems engineers of the relevant systems, to ensure that plans for the SoI align with those of the other relevant systems, particularly the schedules of elements of shared interest.

5.3 Addressing SoS considerations during the production stage

This clause describes the SoS considerations to be addressed in the Production stage as defined in ISO/IEC/IEEE 24748-1:2018, 5.4. Details of the Production Stage from ISO/IEC/IEEE 24748-1 are shown in Box 3.

During production, the design considerations described in the Development Stage need to be monitored to help ensure that changes instituted during the Production Stage do not impact the ability of the SoI to operate effectively as part of the larger systems of systems and that this is confirmed through testing conducted during the Production Stage.

Box 3 Production Stage

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

Production stage (5.4)

Overview (5.4.1)

The Production Stage begins with the approval to produce the system-of-interest. The system-of-interest may be individually produced, assembled, integrated, and tested, as appropriate, or may be mass-produced. Planning for this stage begins in the preceding stage. Production may continue throughout the remainder of the system life cycle. During this stage, the system may undergo enhancements or redesigns, the enabling systems may need to be reconfigured and production staff re-trained in order to continue evolving a cost -effective service from the stakeholder view.

It is presumed that the organization has available the budget and enabling systems that consist of production equipment, facilities, tools, processes, procedures and competent human resources. These items are developed or acquired in order to be available when needed to enable production.

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Purpose (5.4.2) The Production Stage is executed to produce or manufacture the system-of-interest, test it and produce related enabling systems as needed. **Outcomes** (5.4.3) The outcomes of the Production Stage are listed below. a) Plans and exit criteria for the Production Stage. b) Qualification of the production capability. c) Acquisition of resources, material, services and system elements to support the target production quantity goals. d) The system produced according to approved and qualified production information. e) Packaged product transfer to distribution channels or acquirer. f) Updated concepts for execution of all succeeding stages. g) Current risks and mitigating actions identified. h) Quality assured systems-of-interest accepted by the acquirer. i) Satisfaction of stage exit criteria. j) Approval to proceed to the appropriate stage or stages, based on the specific life cycle model in use by the project.

5.4 Addressing SoS considerations during utilization and support stages

5.4.1 General

This clause describes the SoS considerations to be addressed in the Utilization and Support Stages as defined in ISO/IEC/IEEE 24748-1. See Boxes 4 and 5.

5.4.2 Utilization and support stage capability considerations

The considerations about capability context and its impact on the SoI are revisited to assess changes which affect the system.

— Has the current or future operational context for use of the SoI changed (including threat, environment, usage, etc.)? If so, do the changes impact the way the SoI needs to work with other systems supporting the user capability?

Identification of changes in the SoI context and its potential impact on SoI requirements and dependencies will provide a solid basis for planning for upgrades or changes in the SoI to meet current and future user needs. Without an understanding of changes (current and planned) in how the users conduct operations and support and how they use the SoI, there is a risk that beneficial changes to the SoI may be missed, leading to a reduction in its effective capability. There should be available documentation of the current operational concept and support (sometimes documented in Concepts of Operation, Use and Support) with delineation of how the SoI is expected to work in the context of other systems, in the current and planned operational context. If this has not been addressed, validate and update descriptions of the operational concept. If available, the Concepts of Operation, Use and Support should be updated accordingly.

— Are the non-material aspects that contribute to capability (i.e. other lines of development such as Training, Logistics, etc.) mature and aligned so that the capability is being fully exploited as planned?

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Identify whether any of the other non-material aspects of the capability are affecting the ability of the SoI to meet the user need. Examining the effectiveness of the non-material aspects (including any planned changes to these, such as operations, business processes, staffing levels and skills, life cycle support, etc.) helps to avoid the risk that the SoI will fail to deliver the required capability. Periodic assessments of the maturity and effectiveness of the non-material aspects of the capability in which any planned changes (e.g., staffing or education levels) should be taken into account. Changes made to the non-material aspects of the SoI to improve the capability (e.g., improved training) or changes made to the physical system to improve the effectiveness of the non-material aspects (e.g., changes made to the user interface to improve training effectiveness) need to be reviewed and considered in any updates to the SoI.

— Is the SoI playing the role in the SoS as expected? Or are there other systems which are fulfilling the role of this system, and hence, the SoI might be considered for retirement?

— Are SoI changes arising from the evolution of other constituent systems being effectively addressed?

Over time additional systems may play a role in achieving the user capability and may make the need for the SoI obsolete. During utilization and support, the continued need for the SoI to support the SoS should be monitored and if it is no longer playing a needed role in the SoS, the SoI should be considered for retirement.

Box 4 Utilization stage

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

Utilization stage (5.5)

Overview (5.5.1)

The Utilization Stage begins after installation and transition to use of the system. The Utilization Stage is executed to operate the product at the intended operational sites to deliver the required services with continuing operational and cost effectiveness. This stage ends when the system-of-interest is taken out of service.

Planning for this stage begins in the preceding stages. This stage includes those processes related to use of the system to provide services, as well as monitoring performance and identifying, classifying and reporting of anomalies, deficiencies, and failures. The response to identified problems includes taking no action; maintenance and minor (low cost/temporary) modification; major (permanent) modification and system-of-interest life extensions, and end-of-life retirement.

During this stage the product or services can evolve giving rise to different configurations. Enabling systems may likewise evolve. The operator operates the different configurations and the responsible product supplier manages the status and descriptions of the various versions and configurations of the product or services in use.

It is presumed that the organization has available the utilization stage enabling system which consists of facilities, hardware and software, processes, procedures, trained personnel and instruction manuals. These items are developed or acquired in order to be available when needed to support utilization.

Purpose (5.5.1)

The Utilization Stage is executed to operate the product, to deliver services within intended environments and to ensure continuing operational effectiveness.

Outcomes (5.5.1)

The outcomes of the Utilization Stage are listed below.

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a) Plans and exit criteria for the Utilization Stage.

b) Experienced personnel with the competence to be operators in the system-of-interest and provide operational services.

c) An installed system-of-interest that is capable of being operated and of providing sustainable operational services.

d) Performance and cost monitoring and assessment to confirm conformance to service objectives.

e) New opportunities for system-of-interest enhancement through stakeholder feedback.

f) Current risks and mitigation actions identified.

g) Satisfaction of stage exit criteria.

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

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Box 5 Support Stage

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

Support stage (5.6)

Overview (5.6.1)

The Support Stage begins with the provision of maintenance, logistics and other support for the system-of-interest's operation and use. Planning for this stage begins in the preceding stages. The Support Stage is completed with the retirement of the system-of-interest and termination of support services.

This stage includes those processes related to providing services that support utilization of the system-of-interest. This stage also includes processes to use and monitor the support system itself and its services, including the identification, classification, and reporting of anomalies, deficiencies, and failures of the support system and services. Actions to be taken as a result of identified problems with the support system include maintenance and minor modification of the support system and services, major modification of the support system or services, and end-of-life retirement of the support system and services.

During this stage the support system and services can evolve under different versions or configurations. The support organization operates the different versions or configurations and the responsible product organization manages the status and descriptions of the various versions and configurations of the support system and services in use.

It is presumed that the supporting organization has available the enabling systems, which consist of facilities, equipment, tools, processes, procedures, trained support personnel, and maintenance manuals. The items making up the support enabling system are developed and acquired in order to be ready when needed to support the system-of-interest.

Purpose (5.6.2)

The Support Stage is executed to provide logistics, maintenance, and support services that enable continuing system-of-interest operation and a sustainable service.

Outcomes (5.6.3)

The outcomes of the Support Stage are listed below.

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a)	Plans and exit criteria for the Support Stage.
b)	Trained personnel who will maintain the system and provide the support services.
c)	Organizational and enabling system interfaces for problem resolution and corrective actions.
d)	Maintained product and services and the provision of all related support services, including logistics, to the operational sites.
e)	Identification of problems or deficiencies, informing appropriate parties (user, development, production, or support) of the need for corrective action.
f)	Product and service maintenance and corrected design deficiencies.
g)	All required logistics support provided, including a spare parts inventory sufficient to satisfy operational availability goals.
h)	Current risks and mitigating actions identified.
i)	Satisfaction of stage exit criteria.
j)	Approval to proceed to the appropriate stage or stages, based on the specific life cycle model in use by the project. Ordinarily, this would be the Retirement Stage.

5.4.3 Utilization and support stage technical considerations

Technical considerations at this stage include impacts of changes in the SoI's context on SoI needs and performance expectations.

— If there have been changes in the operational context of the SoI, how do these changes affect the SoI?

— Does the ongoing evolution of the SoI consider the ability to influence changes in associated constituent systems, infrastructure or non-material factors?

The same factors considered in system requirements and design may drive the need for changes in the SoI if there are changes in the environment where the system operates while the SoI is in utilization or support. As noted earlier, these include: physical requirements (e.g., size, weight, cooling, power limits), electronic requirements (e.g., signature, interference, etc.), information exchange and management (e.g., network, bandwidth, information needs, etc.), safety, system assurance (e.g., security, information assurance, system integrity), reliability and availability (e.g., to maintain business and operational continuity) and protocols and standards.

Understanding the effect of changes in the operational or business context is key to assessing whether these require changes in the SoI for it to provide continued effective capability for the user. If the SoS context has changed and the impacts on the SoI are not addressed, the risk is that the SoI will fail to operate effectively in the user environment to meet user needs. On-going periodic assessments and documentation of the SoI impact of changes in the SoS operational context are important at this stage. If this has not been addressed, document changes in the operational context and the impact on the system, together with the identification of candidate changes to the SoI or SoS required to address these.

— Have there been changes in the technical design or interfaces of other systems in the SoS, which impact the SoI?

— What is the impact of new technologies and the obsolescence of existing technologies on the SoI and the SoS?

— Are there extant SoI internal interfaces which may need to be exposed to support evolving SoS needs? Should these internal interfaces apply standards appropriate for longer-term SoS evolution?

There may be a need to make changes in the SoI to align with technical changes implemented in other systems in the SoS. Depending on the nature of the SoS, continued operations may depend upon synchronised or coordinated technology updates across multiple systems in the SoS. Alternatively, the

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SoI can be designed to support or adapted to allow multiple technology variants to coexist and not affect the system performance. Similarly, there should be an approach to examine new technologies and their impacts on the SoI and SoS as new technologies emerge and as existing technologies reach obsolescence.

5.4.4 Utilization and support stage management considerations

Changes in management also need to be addressed.

- If there are one or more entities with some type of responsibility which spans the SoS which involve the SoI which were established since the SoI was fielded, have these entities been consulted to help ensure the needs of the SoS are considered in the planning for the SoI?
- Are there proposed upgrades to other systems in the SoS which should be factored into upgrades to the SoI?

If capabilities in one or more SoS depend on the SoI, factoring the needs of these SoS into plans for the SoI will help ensure an integrated approach to meeting user needs for all SoS capabilities. Considering the needs of these SoS in in-service review planning helps to avoid the risk that future upgrades to the SoI will fail to support these new SoS user capabilities. Results should be available of on-going periodic in-service review assessments and documentation of the role of the SoI in fulfilling the operational capabilities of all related SoS, including newly established SoS.

- For user requirements which involve other systems (e.g., interfaces, new or changed functionality in other systems), have these other systems made changes or are they planning to make changes which impact the SoI (or vice versa)?
- Do these changes in other systems impact the ability of the SoS to support the user?
- Are ongoing management arrangements between the SoI and SoS/other constituent systems effective?
- Is the level of formality appropriate and are schedule and budget considerations being properly considered?
- Are changes to these arrangements being effectively managed?
- Are management arrangements evolving along with the SoS and new, modified or retired constituent systems?

If aspects of the SoI which are directly related to other systems have changed since the system was fielded, or there are plans in place to make changes, these need to be examined at each in-service review to help ensure the SoI changes are compatible with continued SoS user support. If changes in the SoI are made which potentially impact the SoS (or vice versa), there is the risk that the SoS will no longer provide adequate support to the users. On-going periodic in-service review assessments and documentation of system dependencies within the SoS and review of the status of other systems, which may impact the SoI and vice versa, are all important at this stage.

5.5 Addressing SoS considerations in retirement stage

This clause describes the SoS considerations to be addressed upon entry to the Retirement Stage as defined in ISO/IEC/IEEE 24748-1:2018, 5.7. Details of the Retirement Stage from ISO/IEC/IEEE 24748-1 are shown in Box 6.

Prior to entry into the Retirement Stage, SoS considerations need to be addressed as part of the decision to retire an SoI. In particular, SoS capabilities dependent on the SoI being retired need be reassessed to help ensure that the remaining constituent systems, including new systems being deployed, are able to provide adequate support to maintain the continuity of the capabilities of the SoS.

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If there is an entity responsible for the SoS, prior to a decision to retire the system, an SoI, discussion is needed with the SoS entity regarding the impact on the SoS if the SoI is retired.

Box 6 Retirement stage

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

Retirement stage (5.7)

Overview (5.7.1)

The Retirement Stage provides for the removal of a system-of-interest and related operational and support services, including appropriate disposal of specified system elements. Planning for the Retirement Stage begins in the preceding stages. This stage begins when a system-of-interest is taken out of service.

This stage includes those processes related to operating the system that enables retirement of the system-of-interest (the retirement enabling system), including appropriate disposal of specified enabling system elements, and also includes monitoring performance of that enabling system and the identification, classification, and reporting of anomalies, deficiencies, and failures of the retirement enabling system. Actions to be taken as a result of identified problems include maintenance and minor modification of the retirement enabling system, major modification of the retirement enabling system, and end-of-life retirement of the retirement enabling system itself.

It is presumed that the organization has access to an enabling system, which consists of facilities, tools, processes, procedures, equipment, trained personnel and, as appropriate, access to recycling, disposal or containment facilities. The items making up the retirement enabling system are developed and acquired in order to be ready when needed to perform retirement functions.

This stage is applicable whenever a system-of-interest reaches its end-of-service life. Such end-of-service life can be the result of replacement by a new system, irreparable wear, catastrophic failure, no further use to the user (e.g., through change in mission or business direction), or when it is no longer cost-effective to continue operating and supporting the system-of-interest.

Purpose (5.7.2)

The Retirement Stage is executed to provide for the removal of a system-of-interest and related operational and support services, and to operate and support the retirement system itself.

Outcomes (5.7.3)

The outcomes of the Retirement Stage are listed below.

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a) Plans and exit criteria for the Retirement Stage.

b) Disposal constraints are provided as inputs to requirements, architecture, design, and implementation.

c) Any enabling systems or services needed for disposal are available.

d) Agreement to terminate support services.

e) Residual risks and mitigating actions identified.

f) The system elements or waste products are destroyed, stored, reclaimed or recycled in accordance with safety and security requirements.

g) The environment is returned to its original or an agreed state.

h) Records of disposal actions and analysis are available.

i) Satisfaction of stage exit criteria.

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Annex A
(informative)

System of systems technical base

In the ideal case, artifacts from SoS analysis will be available to understand end-to-end capability objectives, performance metrics and current performance data, systems supporting those objectives, technical baseline, gaps, etc. to provide needed context. At a given point in time, these information artifacts should provide an understanding of:

— the life cycle dependencies among constituent systems of the SoS;

— how constituent systems currently support the capability (including functionality, performance, capacity, interfaces, protocols and standards, data exchanges, etc.) as well as the current SoS concept of operations; that is, how the constituent systems are employed by users in an operational setting to deliver the capability objectives;

— dependencies and interdependencies among constituent systems and material and non-material aspects supporting the capability;

— other capabilities which are dependent on the current constituent systems and non-material resources (or subset thereof) since systems on which this new effort is depending may also be key to other capabilities.

The SoS architecture description provides the framework for understanding how constituent systems support the capability (including functionality, performance, interfaces, data exchanges, etc.). The architecture traces forward to all requirements and specification artifacts and backwards from those artifacts to architecture.

Missing elements of the traceability may highlight areas where the SoS architecture is incomplete (and needs update), or where interpretations differ (needing further explanation, resolution and re-tracing). Interdependencies among systems and non-material aspects supporting capability are fully evaluated and assessed. The architecture artifacts documenting this are part of preliminary and formal reviews; and programmatic aspects of these dependencies are recorded and explicitly worked. Such management includes the use of metrics and processes to evaluate the consistency, completeness and health of the interfaces, whether technical or management in nature.

These may all support the systems engineer of a constituent system to address questions about the impact of the SoS context on aspects of the system at all stages.

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Annex B
(informative)

Example SoS considerations in the life cycle stages of a constituent system

This annex provides an example of addressing SoS considerations in the life cycle of a constituent system in the banking domain. The purpose of this description is to help to understand how SoS considerations could be applied in one case.

In this example, an existing SoS consists of constituent systems - multiple independent banks (A, B, C and D). The four banks have worked together to develop and implement a "Money Transfer SoS" capability. This SoS supports money transfer between personal users, each of which has an account in a different bank. In this example, money transfer is done with account numbers, branch codes and bank codes as follows: the user transfers money, $100, on a given date from account X, branch A-1, bank A to account Y, branch B-1 bank B. The information on bank codes, branch codes and account numbers must be maintained consistently in all banks for the SoS to operate effectively.

In this example, a new independent bank (new system) is being created. In addition to internal banking user services, an important user service is money transfer with other banks, that is, the ability to support customer money transfers to other banks, particularly Banks A, B, C and D.

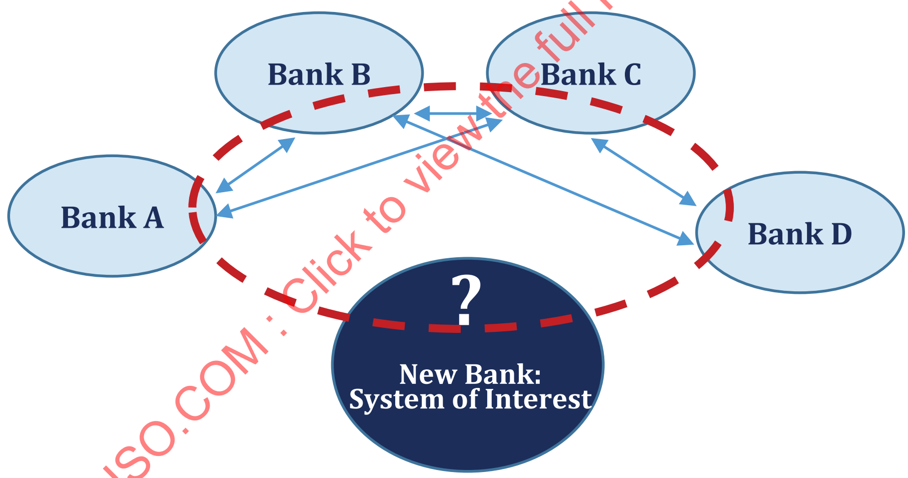

Figure B.1 — Example of the application of SoS considerations to a new bank which will be part of a money transfer system of system

In this example, this document provides guidance on the considerations to be addressed at each stage of the new bank life cycle to help to ensure that the bank, when operational, will be able to provide money transfer services to its users.

For example, during the Concept Stage, the creators of the new bank would address the following:

— Has the business context for the new bank been described including the need for money transfer to other banks?

— Has the existing money transfer capability been described, including the systems that currently support that capability? What are the scenarios?

— How would this new bank system fit into the current interbank money transfer business processes (i.e., money transfer capability provided by the bank SoS)?

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