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Systems and software engineering — Taxonomy of systems of systems

Ingénierie système et logiciel — Taxonomie des systèmes de systèmes

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Foreword

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

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

This corrected version of ISO/IEC/IEEE 21841:2019 incorporates the following correction:

— The publication date on the cover page has been corrected.

Introduction

Systems of systems engineering (SoSE) is a concept that is increasingly thought of as a discipline important for the realization and sustainability of large and persistent sociotechnical systems in areas as diverse as healthcare, transportation, energy, defense, corporations, cities and government.

While SoSE applies broadly to hardware, software, middle-ware as well as embedded, cyber-physical and digital systems, the importance of SoSE has been heightened in the last fifteen years by the rapid increase in the pervasiveness of information technology (IT), illustrated by new technologies and paradigms such as Sensor Networks, Cloud Computing, the Internet of Things, Big Data, Smart Devices and Artificial Intelligence. It is, for instance, the application of these technologies to cities that transform them into “smarter” cities.

This pervasiveness of IT was not only driven by the availability of these technologies, but also more importantly by the requirements in our resource and environmentally-constrained world for increased and sustainable economic development and, ultimately, personal well-being.

SoSE goes well beyond IT and potentially applies to all types of systems, including hardware and cyber physical systems where IT is an enabler. SoSE addresses functionality, performance and interdependencies of the systems as well as their connectivity. The interconnectivity of systems has become pervasive in large command and control systems, defense systems, communications systems, transportation systems and medical/health systems, among others. The accelerating need to share information and leverage capabilities from other systems has changed how systems need to be viewed and engineered.

Taxonomies provide a means in many fields to classify and describe the relationships among the relevant elements being studied. The elements of a taxonomy, or taxa, form a partitioning or means of classification within that body of knowledge. In the context of systems of systems (SoS), the relevant elements of the system of interest are, by definition, systems themselves. Using essential characteristics to partition the various types of SoS provides an abbreviated nomenclature for thinking about SoS. Based on taxonomies, different approaches to the engineering of systems of systems are possible, improving the efficiency and effectiveness of systems of systems engineering.

Systems and software engineering — Taxonomy of systems of systems

1 Scope

This document defines a normalized taxonomy for systems of systems (SoS) to facilitate communications among stakeholders. It also briefly explains what a taxonomy is and how it applies to the SoS to aid in understanding and communication.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

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

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

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

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

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

3.1 General terms

3.1.1
constituent system
CS
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* (3.1.3), utilization, goals, and resources, but interacts within the SoS to provide the unique capability of the SoS.

[SOURCE: ISO/IEC/IEEE 21839:2019, 3.1.1, modified — The abbreviated term "CS" has been added.]

3.1.2
governance
process of establishing and enforcing strategic goals and objectives, organizational policies and performance parameters

Note 1 to entry: This definition is adapted from Reference [8].

3.1.3
management
system of controls and processes required to achieve the strategic objectives set by the organization's governing body

Note 1 to entry: Management is subject to the policy guidance and monitoring set through corporate *governance* (3.1.2).

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

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 interaction of the constituent systems in the system of systems.

[SOURCE: ISO/IEC/IEEE 21839:2019, 3.1.4]

3.1.5
systems of systems engineering
SoSE
process of planning, analyzing, organizing, developing and integrating the capabilities of a mix of existing and new systems, including inter-system infrastructure, facilities, and overarching processes into a system-of-systems capability that is greater than the sum of the capabilities of the *constituent systems* (3.1.1)

Note 1 to entry: This definition is adapted from Reference [9].

Note 2 to entry: SoSE also includes testing, modification, maintenance and other post-integration activities.

3.1.6
taxonomy
scheme that partitions a body of knowledge and defines the relationships among the pieces

[SOURCE: ISO/IEC/IEEE 24765:2017, 3.4167, modified — Definition 2 has been removed; Note 1 to entry has been removed.]

3.2 SoS types

3.2.1
acknowledged system of systems
acknowledged SoS
SoS (3.1.4) with recognized objectives, a designated manager, and resources for the SoS

Note 1 to entry: *Constituent systems* (3.1.1) retain their independent ownership, objectives, funding, and development and sustainment approaches. Changes in the systems are based on cooperative agreements between the SoS and the system.

Note 2 to entry: This definition is adapted from Reference [7].

3.2.2
collaborative system of systems
collaborative SoS
SoS (3.1.4) in which component systems interact more or less voluntarily to fulfill agreed-upon central purposes

Note 1 to entry: *Constituent systems* (3.1.1) collectively decide how to provide or deny service, thereby providing means of enforcing and maintaining consistency.

Note 2 to entry: This definition is adapted from Reference [7].

3.2.3
directed system of systems
directed SoS
SoS (3.1.4) created and managed to fulfill specific purposes and the *constituent systems* (3.1.1) are subordinated to the SoS

Note 1 to entry: Component systems maintain an ability to operate independently; however, their normal operational mode is subordinated to the central managed purpose.

Note 2 to entry: This definition is adapted from Reference [7].

3.2.4
virtual system of systems
virtual SoS
SoS (3.1.4) that lacks a central *management* (3.1.3) authority and a centrally-agreed-upon purpose for the SoS

Note 1 to entry: Large-scale behavior emerges—and can be desirable—but this type of SoS relies on relatively invisible mechanisms to maintain it.

Note 2 to entry: Virtual SoS are typically self-organizing.

Note 3 to entry: This definition is adapted from Reference [7].

4 Concepts and application

4.1 Overview

Taxonomies provide a means in many fields to classify and describe the relationships between the relevant elements being studied. The elements of a taxonomy, or taxa, form a partitioning or means of classification within that body of knowledge. Partitioning based on essential characteristics provides an abbreviated nomenclature to refer to a larger composite of characteristics, facilitating discussion about the partitions (taxa) without having to refer to each of the characteristics.

4.2 Importance of taxonomies to SoS

In systems engineering (SE), the relevant pieces of the system of interest can be called subsystems, elements or components. In the context of SoS, the relevant pieces of the system of interest are, by definition, systems themselves. These are called constituent systems (CS) throughout this document. That is, an SoS consists of some number of CS, plus any inter-system infrastructure, facilities and processes necessary to enable the CS to integrate or interoperate. Relationships between CS affect the SoS. Using essential characteristics to partition the various types of SoS provides an abbreviated nomenclature for thinking about SoS. While Clause 5 elaborates one mature SoS taxonomy, Annex A provides a list of SoS less-mature taxonomies. Based on taxonomies, different approaches to the engineering of systems of systems are possible, improving the efficiency and effectiveness of SoSE.

NOTE 1 Taxonomies can have some overlap in their definition and need not be orthogonal to each other to be useful. An SoS can be considered as belonging to several taxonomies as long as its characteristics meet the definitions of the taxonomies.

NOTE 2 It is possible that inter-system infrastructure, facilities and processes do not meet the criteria for being systems in their own right. From the perspective of the SoS, these could be system elements (or SoS elements).

4.3 Use of SoS taxonomies

There are many characteristics such as scale and scope, around which taxonomies can be derived. The SoS taxonomy in Clause 5 organizes the relevant aspects or essential characteristics of SoS, providing