RECOMMENDED DEFINITIONS OF "SYSTEM" AND "SYSTEMS ENGINEERING"

INTRODUCTION

The Fellows Initiative on System and Systems Engineering Definitions was established in 2016 to:

1. review current INCOSE definitions of SYSTEM and SYSTEMS ENGINEERING; and
2. recommend any changes necessary to align the definitions to current practice and to the aspirations of INCOSE's 2025 Vision (INCOSE 2014).

We conducted a detailed review and assessment of existing definitions of SYSTEM, including the existing INCOSE one and many others. We also canvassed opinion, informally and by a structured survey, from the INCOSE Fellows and members of the Systems Science Working Group (SSWG) on what they identified as essential attributes of a system.

We concluded that we do need to refresh INCOSE's definition of *system*, and furthermore, that the new definition should be in two parts: a general definition of *system*, and a specific definition of "*engineered system*". A new definition of *systems engineering* then ties in with the specific definition of *engineered system*.

Each of these new definitions is expressed as a short summary statement with amplifying notes. The summary versions of the definitions are given here, while the full versions will be found later in the document.

System (DEF): *a system is a collection of inter-related parts that, by virtue of the relationships between them, does things its parts cannot do on their own*.

Engineered System (Def): *An engineered system is a SYSTEM [as defined above] composed of a related set of parts designed to interact with the operational environment in order to achieve an intended purpose and deliver value to beneficiaries, while doing minimal harm, complying with applicable constraints, and meeting specified conditions.*

Systems Engineering (DEF): *Systems Engineering is a transdisciplinary approach that applies systems principles and concepts to enable the successful realization and use of engineered systems and whole-system solutions.*

This document seeks to give the essential information required by stakeholders to understand what we have proposed and why. Those wishing more detail are directed to the references, and to the draft papers which will become available once the IS18 review process is completed.

EXISTING SYSTEM DEFINITIONS AND WORLDVIEWS

We reviewed literally hundreds of definitions of system. These tend to cover one or more of three aspects:

- The structural aspect: What a **System IS** – focus on structure – referring to multiple inter-related elements and their properties;
- The behavioral aspect: What a **System DOES –** focus on behaviour – this aspect of the definitions usually involves the notion of emergence, namely, the things which the system does as a whole which its parts cannot do separately, and sometimes also involves complex dynamic processes that maintain stability and viability in the face of external disturbances;
- The axiological aspect: **Why a system EXISTS** – focus on purpose, value or utility - these notions are problematic for a general definition of system, because they can only be safely attributed to deliberately constructed "artificial" systems.

The more we probed, the more we realized that there are many types of systems and many styles of definition, and that INCOSE does not have a monopoly on the concept of *system*. Most of the definitions we studied were not general, but seemed to be grounded, usually implicitly rather than explicitly, in specific **worldviews**. (A person's worldview is the way they see and understand the world.) Consequently, most of the definitions, and the key criteria used to categorise them, refer not to systems in general but to specific system subtypes. For example, we found the following kinds of systems:

- Systems that occur in the "real" (physical) world
- Systems that are mental constructs, including representations of reality and models of "real" systems
- Systems that consist of pure information
- Systems whose boundaries or elements are observer-designated
- Systems whose boundaries or elements are discoverable based on objective criteria
- Systems that are simply "parts standing in relation" (to each other)
- Systems that have complex dynamic properties

We issued a survey on System Worldviews to the Fellows and the SSWG. Over 85% of the 26 Fellows who responded, and over 80% of all who responded to the survey, agreed that the following statements are defining aspects of "system".

- A system is composed of more than one part.
- There are relationships between the parts of a system.
- Interactions occur between the parts of a system (though some argued convincingly that interaction is only a property of "real", not of "conceptual" systems).
- A system exhibits "emergent properties": properties of the whole system not possessed or exhibited by the individual parts acting separately.

in the systems community "emergent properties" has two distinct meanings: one being only those properties that you could not have predicted, which gives rise to "surprising," often undesirable consequences; the other being ALL the properties at the system level that are due to the parts interacting or inter-relating in a systemic fashion to give properties that the parts do not possess. The second meaning is the one intended in this paper.

Other characteristics of "system" that respondents regarded as "defining" varied radically. About a dozen additional criteria were offered as possible "defining characteristics". None of these scored over 70% among the Fellows or 71% overall, only two scored over 50%, and most scored much lower. There are strong patterns and clustering in the data, and our analysis suggests that selection or not of these additional criteria is highly worldview-dependent.

DIVERSE "SYSTEM" WORLDVIEWS IN INCOSE

We discovered at least seven different worldviews on *system* held within the INCOSE community:

1. **A formal minimalist view –** based on mathematics and logic
2. **A constructivist view –** based on the claim that a system is a purely mental construct
3. **A moderate realist view** - claiming that systems exist in both physical and mental "worlds"
4. **An extreme realist view** – claiming that systems exist only in physical world
5. **A complex, viable, "living systems" view** – claiming that systems must possess viability, adaptivity, and livelihood features, and therefore are inherently complex, e.g., Miller's "Living Systems" (1978)
6. **A mode of observation view** – claiming that a system is merely a way of seeing something – Aslaksen (2013), Weinberg (2001)
7. **A process view** - claiming that a system is a process (Blockley, 2010)

We submitted a paper to IS 18 on the data and analysis that identifies and characterizes these worldviews.

"OPEN OUR MINDS": IMPLICATIONS FOR A "CONSENSUS" OR GENERAL DEFINITION

At this point, we ask the reader to please suspend disbelief, open your mind, and look for value in the worldviews you don't agree with. It is not possible to "prove" which of the above worldviews is correct and which are not; they are different ways of viewing the same world, depending on the individual's interests and concerns, their educational and cultural backgrounds, and their basic philosophical disposition.

On the one hand, if we were to choose a definition matching any one of the worldviews listed above, we would have to reject the views of many members of the systems community. The definition would exclude things that some systemists regard as important examples of "system", and make it difficult for systems engineers to learn from researchers who do not share our chosen worldview.

On the other hand, a general definition of "system" that aims to accommodate the full range of worldviews might appear too wide to most practitioners. It would not include features of "system" that you might believe are essential, and might include as *system* things that you think are not systems. Please bear with us while we first propose a very general definition for "system", then focus in on various types of "interesting" systems, and finally propose a new definition for "engineered system".

PRIOR INCOSE DEFINITION OF SYSTEM

The current INCOSE definition for *system* is as follows.

A system is an integrated set of elements, subsystems and assemblies that accomplish a defined objective. These elements include products (hardware, software, firmware), processes, people, information, techniques, facilities, services, and other support elements.

Clearly, this is not a general definition of "system", as it refers only to certain types of engineered systems.

Key issues with this definition include that it:

- is couched in terms of "real" systems;
- further restricts its scope to artificial (human-made) technology-based systems;
- is not compatible with wider system science definitions, thereby limiting transfer of knowledge across disciplines.

Further critique of this definition includes the following issues:

- It is restricted to purposeful human-made systems and excludes naturally occurring systems, since the latter do not have an 'a priori' defined objective.
- It does not include naturally occurring elements, which are often embodied in engineered systems.
- It does not recognise that an engineered system is an open system, which accomplishes its defined objective by interacting with a wider context or environment.
- It does not recognise unintended consequences that may arise from unplanned or ignored interactions among system components.

DEVELOPING A NEW FAMILY OF DEFINITIONS OF *SYSTEM* FOR INCOSE

Our initial effort was to develop a family of definitions related to different system types. As we engaged in this effort, several issues arose. It was hard to find one good root definition that is common to conceptual systems ("systems of pure information") and real systems ("systems of matter and energy"). Language was a big issue too. In terms of basic system types, we were guided by language used by Bertalanffy in his discussions of General Systems Theory. Wherever practical, to make the definitions accessible, we try to use words as they are interpreted in everyday language.

Our first year's work was published in the proceedings of the 2017 INCOSE International Symposium in Adelaide (Sillitto et al, 2017) and the SE Journal (Dori & Sillitto, 2017). Since then, we have revisited our definitions to improve accessibility of language, proposed a new strawman definition of "general system" and "engineered system", and checked the mapping of our ideas to the Basic Formal Ontology (BFO) described by Arp, Smith and Spear (2015). Our immediate focus is to wrap up the current stage of our work in early 2018, but there is clearly a potential to build further on this work.

We now develop a multi-stage approach to INCOSE's new definition of *system*. First, we provide a very general form of definition intended to embrace all worldviews, or at least those we had identified. Then we note key features and some important specialisations of systems. Finally, we propose a specific definition for "engineered systems".

A VERY GENERAL DEFINITION OF "SYSTEM" AIMING TO INCLUDE ALL WORLDVIEWS

The following is a general, minimalist, definition of *system* that is as universal as possible, to accommodate and respect the wide range of worldviews in the Systems Engineering and Systems Science communities.

SYSTEM (DEF): *a system is a collection of inter-related parts that, by virtue of the relationships between them, does things its parts cannot do on their own*.

Notes:

a. *A system is described by four sets of features:*
    i. a *set of PARTS;*
    ii. *a set of INTERNAL RELATIONSHIPS between and among the PARTS, and between the PARTS and the SYSTEM as a whole;*
    iii. *a set of EXTERNAL RELATIONSHIPS between the SYSTEM and its ENVIRONMENT(S);*
    iv. *a set of PROPERTIES that arise because of these RELATIONSHIPS.*
b. *A system may be "real", composed of matter and energy; or "conceptual", a product of thought consisting of pure information; or a composite of both types, where conceptual parts (e.g., information elements such as software, policies, or procedures) are used to control (or influence, if strict control is not possible) the system's material parts and their behaviour.*
c. *A system may be closed or open. A closed system has no significant external relationships or interactions. An open system can relate to, and in the case of real systems interact with, external entities.*
d. *The word environment and context are treated as near synonyms in Systems Engineering. The everyday definition of "environment", and that given in www.sebokwiki.org, fit our purpose better than the everyday definition of "context".*
e. *In a "real system", properties, capabilities and behaviours can "emerge" because of interactions between the parts of the system or between the system and its environment, involving the exchange of material, energy and information. New properties can also emerge due to interactions between the properties of the system (Hall & Fagen, 1956).*
f. *A system's"capability" is its ability to do something, while "behaviour" is the system's response to stimulus. The behaviour may be a process, e.g., to perform a required function, provide a required output, or counter the adverse effect of the stimulating event. For example, the human body is capable of perspiring, which counters the adverse effect of overheating.*
g. *In "conceptual systems", the property that "emerges" because of RELATIONSHIPS between the parts is MEANING not conveyed, or CONTROL not achieved, by the parts on their own.*
h. *Conceptual systems include mental or mathematical models of real or intended systems, process instructions, software code, organisational design, as well as ideas, literary works, and other products of thought.*
i. *Conceptual systems are generated, modified and used by processes involving real systems.*
j. *Conceptual systems must be recorded or hosted in some physical medium.*
k. *Conceptual systems may generate capabilities and behaviour when hosted in real systems.*
l. *A system may be a part of another system, and its parts may be considered as systems.*
m. *A collection of parts without relationships between them that cause systemic properties to arise is not a system and is sometimes referred to as "a heap".*

A FURTHER NOTE ON "RELATIONSHIPS"

Relationships both internal and external to a system can be of various kinds, such as political, economic, social, cultural, technological, environmental, legal, mathematical, ecological, etc.

A relationship to a part has two aspects: the connection to the entity itself, and the connection to the properties of that entity. In some cases, for example, what is important is connections between two parts (e.g., how they touch, distance between their centers, gravitational force between them). In other cases, for example, what is important is connections between the properties of two parts (e.g., temperature of one part affects temperature of another part, color or shape of one part affects another part's ability to see the other part).

Relationship of parts to the system as a whole can be of various kinds, such as composition, aggregation, spatial, temporal, causal, ownership, responsibility, accountability, etc. For example, each part can have a distance to the center of gravity of the whole, while the center of gravity (of the whole) is a function of these distances and the mass properties of the parts.

A description of the system should consider all possible relationships with all possible environments. Not all of these relationships will generate behaviour at any particular time, or in all of the possible environments. As a specific example of this, consider the example of "susceptibility to EMI".

- No EMI source = no interaction = no degradation due to EMI.
- Unforeseen EMI source + susceptibility to EMI = system degradation due to EMI.

So we can say that "susceptibility to stimulus" is a property of the system, while "interaction leading to an effect" is context dependent - it depends on the actual properties and state of a particular example of the system and of its real environment at a particular time.

SOME INTERESTING CASES

CONCEPTUAL SYSTEMS - SYSTEMS OF PURE INFORMATION

A conceptual system is the product of thought (by humans or other sentient beings). In its pure form, a conceptual system is composed of pure information – no physical subsystems, no material or energy, just structured information. The boundary of a conceptual system is designated by the conceiver of the system. The minimum content of a conceptual system is the information content (the informatic elements and the relationships between them), the syntactic rules for structuring them and the semantics for interpreting the information.

Examples of such "conceptual systems" include:

- relationships between letters to form words
- relationships between words to form sentences, paragraphs, chapters and books
- relationships between axioms to form a theory
- relationships between equations to form a system of equations or a mathematical model
- relationships between lines of code to form a computer programme
- a matrix of numbers or mathematical expressions
- relationship between elements of belief to form a belief system (religion, politics, philosophy, etc.)
- a model of a real system
- a model of a conceptual system.

Conceptual systems can exist in the form of mental models, informally structured shared information, and formally structured shared information (Fig 1). Bertalanffy defines an interesting and important subclass of conceptual system, the "abstracted system", which is "an abstraction" of a real system or of a part of the real world viewed as a system. Examples of these are shown in the table below.

Conceptual System Subtype	Definition	Examples
Mental model	Concepts and ideas existing in the mind of an individual sentient being	*How we think a computer or a car works, perception of how other people see us, an initial concept of a system design.*
Informal shared information	Concepts and ideas shared with other sentient beings as informally related information objects.	*A book, drawings or sketches, photographs, a speech, a video recording, minutes of a meeting, a song or ballad or story or legend, a system of beliefs (religious or political).*
Formal shared information	Concepts and ideas shared with others as a set of formally related information objects.	*Computer programme, mathematical proof, 3-D solid model of a physical artefact, executable simulation of an electronic circuit or a physical system, a system of equations (e.g. Maxwell's Equations), a conceptual model of a system in a formal language (e.g., a UML or OPM model).*
Abstracted system	Conceptual system that corresponds to (i.e., is an abstraction of) a Real System – may take any of the above forms.	*A system architecture, an organisation chart, the set of design information artefacts for a product, a mental or mathematical model of an observed or postulated physical phenomenon, a diagram or sketch of a real world system (e.g. exploded view of a spacecraft or jet aircraft).*

"Pure information" needs to be encoded in physical form to be stored, shared and transported; so we can talk about the "information content", which is pure information, and "information artefacts" which are information content encoded as material or energy states in a physical medium such as a storage device or a physical communication channel.

A good example would be the book 'Huckleberry Finn'. The 'information content' is invariant. It is contained or 'instantiated' in numerous 'information artefacts' - paper books, computer files, etc. Another dimension of variation of the 'system' is the different print and electronic editions of the book that have appeared over the years.

So, the book is the **product of thought**. The **process of thought** to create and perfect it happened in Mark Twain's mind; and numerous copies of the information content now exist in the form of paper books, electronic files, memories in people's minds, etc.

Some forms of conceptual systems, once created, motivate or control the behaviour of “real systems”. Examples include computer programs, process instructions, systems of religious and political beliefs, and the genetic information encoded in DNA.

PURE INFORMATION SYSTEMS – SYSTEMS THAT CREATE AND USE INFORMATION

If we think about how information is created, modified and used, we can develop the concept of a “pure information system” as the minimum system that can create, use and modify information. This is a composite system whose parts include both conceptual and real subsystems. The minimal set of parts of such a system is the information content, a storage medium, a processing element, the syntax rules for structuring the information and the semantics for interpreting the information. The essential characteristics of such a system can be described as follows (thanks to Mike Delamare for this).

1) The unitary, distinct elements of information or data that are not connected are just a heap.
2) Information must be connected and have some structure to become a system.
3) The act of making and breaking connections in space and time is a fundamental behaviour of a pure information system. We can call this behaviour reasoning (or choose a simpler term that does not connote sentience). Without this behaviour, no system of information can exist and we are left with a heap.
4) As more information is connected and disconnected, the structure changes. So also can the reasoning become more sophisticated (or complex). This makes an information system able to adapt.
5) The essence of a “conceptual system” can be defined as the information items it is composed of, the connections between these items, and the rules by which connections can be created and eliminated.
6) The elements in a “pure information system” are objects – things that exist, physically or conceptually – and processes – operations that over time transform objects by creating or consuming them, or by changing their states.
7) Connecting new information with previous information changes the structure of the information and can alter behaviours. This is a form of learning, and it allows the system to adapt its behaviour as its knowledge of the world improves.

REAL SYSTEMS – SYSTEMS OF MATTER AND ENERGY

Real systems are composed of matter and energy, and are considered to exist in the physical world of space-time. They may be “artificial” (made by human or other agents), “naturally occurring”, or a hybrid of both.

- Deliberately constructed “artificial systems” are intended for a purpose.
- Unintended systems are created when intended systems are unintentionally coupled with each other or with naturally occurring systems, leading to unintended emergent properties that are usually unwanted and potentially harmful.

As systems engineers, we are interested in other systems besides those that we engineer, for three reasons.

First, systems engineering may involve modifying an existing naturally occurring or artificial system for a purpose. Success in such cases requires that we understand the existing system before we try to change it.

Second, we can sometimes use successful existing systems as patterns for those we want to develop.

And third, the study of systems in general has the potential to provide a scientific underpinning to improve the practice of systems engineering.

Thus, we need a common language and set of concepts that we share with those who study systems in general, to describe, understand and learn from various types of naturally occurring and spontaneously emerging systems.

We examined two possible typologies or taxonomies for real systems. As both have merits, we briefly present both of them in the following paragraphs.

REAL SYSTEM TAXONOMY BASED ON ORIGIN (NATURAL VS. ARTIFICIAL)

The first possible taxonomy depends on the origin of the system (Figure 1, which also shows conceptual systems as analysed above).

In the realist view, systems exist in the real world, regardless of whether they are identified as such by human observers. Hence, we distinguish between "all real systems" and those that are "recognised" by sentient observers. Real systems may be naturally occurring, or artificial, or they may be a hybrid of the two. A "hybrid system" may have attained its present form through artificial influence, such as selective breeding, or artificial modification, such as genetic engineering. The table below offers examples of each type.

Real System Subtype	Definition	Examples
Naturally occurring system	A real system occurring in nature	*The universe, the solar system, our planet, human beings, ants, ant colony, atoms; systems that exist in nature that we have not yet recognised.*
Artificial system	A real system created by sentient beings	*Aeroplanes, airlines, air defence systems, cities, cars, ships, cameras, computers, a beaver dam*
Hybrid system; two subtypes	A system that has attained its current form through a combination of natural and artificial influences	*See below.*
Modified naturally occurring systems	Hybrid systems created by modifying elements of naturally occurring systems, or modifying arrangements of these elements	*genetically modified crops and animals, ornamental garden, shipping canals*
Influenced naturally occurring systems	Naturally occurring systems **influenced** by actions of sentient beings and/or systems made by them.	*selectively bred crops and animals; the water flow downstream of a dam or flood prevention system*

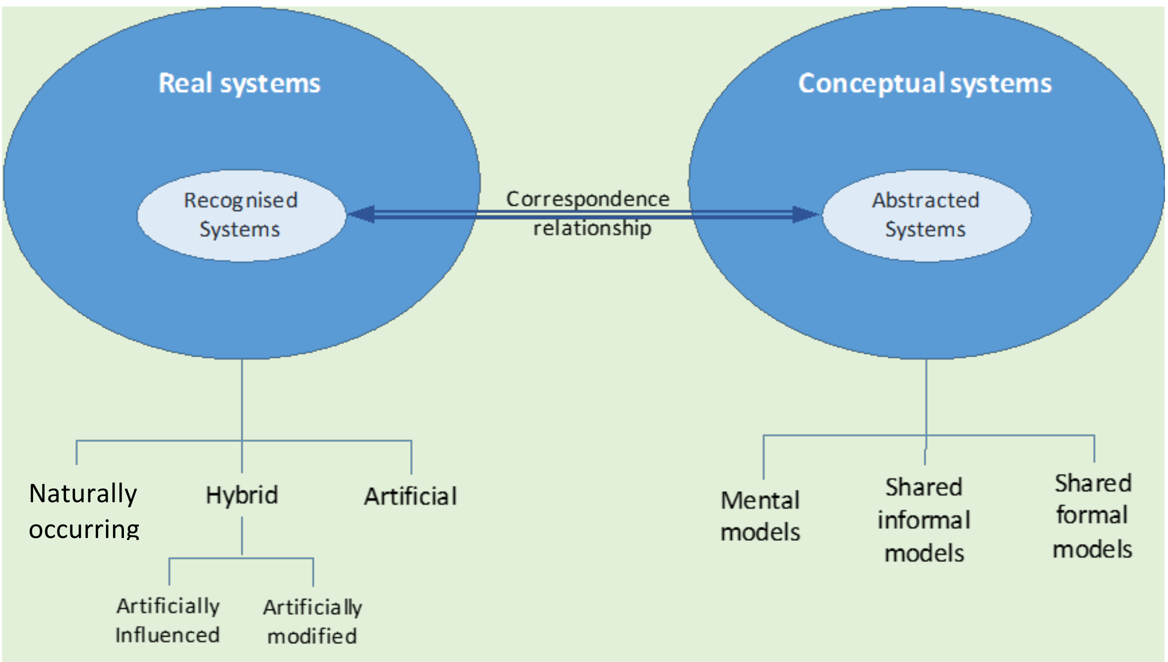

Figure 1: systems classified by origin

REAL SYSTEM TAXONOMY BASED ON CHARACTERISTICS OF SYSTEM

A different approach is to consider the nature of the system, trying to find cohesive groupings of different system types with different sets of "systemic characteristics".

It is possible to make a broad distinction between two categories of system types:

- systems with explicit information processing and decision-making subsystems, that have the potential to anticipate future changes in the environment to prepare for changes before they occur, and/or to actively influence their environment to counter any expected "opposing forces";
- systems without explicit information processing and decision-making subsystems, that can only resist or react to changes in their environment.

While it may not be possible to make a sharp distinction between these two categories, some widely recognised types of system seem to fall within each category:

- systems with explicit information processing and control subsystems, such as
    - "Living Systems" (Miller, 1978),
    - social and societal systems, and
    - "technological systems" involving information and control processing, sensors and effectors;
- systems with no explicit information processing subsystems, such as
    - passive structural systems (e.g. civil engineered structures)
    - ecosystems (NB these still have complex, decentralised, regulation mechanisms), and
    - geological and "physical", non-biological systems (e.g. atoms, molecules, aerodynamics, plate tectonics).

PRACTICAL ENGINEERED SYSTEMS ARE "COMPOUND SYSTEMS"

Practical engineered systems usually include elements of several of these types. While systems engineering has tended to focus on "technological systems", it is now increasingly concerned with relationships between all of these types, particularly the interactions between social and technological systems. We choose to call systems that include more than one system type, "composite systems".

We can draw a useful analogy with Chemistry. The "Periodic Table of the Elements" lists the "elements" from which "compounds" and "alloys" are formed. Most material in nature exists as compounds rather than as elements, and many engineered materials are alloys. Similarly, most systems in the real world, at least in a realist perspective, are compounds of more than one of the "elemental system types". Most engineered systems include both physical and "pure information" elements. Modern civil engineering systems include information processing elements, for example to monitor the condition of the structure and to control traffic. The term "socio-technical system" denotes a system with both technological and social/societal elements, and the study of certain aspects of these systems.

The reason why it is important to understand the nature of these different 'elemental system types" is that they have different inherent characteristics and types of relationships, and respond to different kinds of stimuli over different time constants. Hence, they need different management and control strategies. For example, technological systems are "controlled", but people and societal systems respond better to influence (rather than being directly controlled). Failure to match management and control strategies to the variety inherent in the system of interest is a major cause of system failure. This has huge implications for the systems engineering of "composite systems".

RECOMMENDED DEFINITION OF ENGINEERED SYSTEM

Finally, we propose a definition for the form of system that is the focus of Systems Engineering, the *engineered system.*

Engineered System (Def): *An engineered system is a SYSTEM [as defined above], composed of a related set of parts designed to interact with the operational environment in order to achieve an intended purpose and deliver value to beneficiaries, while doing minimal harm, complying with applicable constraints and meeting specified conditions.*

Notes:

a. *The system parts may include hardware, software, firmware, processes, people, information, techniques, facilities, services, other support elements, and (usually modified) naturally occurring elements.*
b. *The system should be fit for purpose - e.g. fail safely, be resilient, provide sustainable value to intended beneficiaries, facilitate achievement of desired outcome, and do minimal harm to the beneficiaries, other stakeholders, society in general and the natural world.*
c. *The system should be compatible with relevant constraints - e.g., cost, schedule, risk, physical installation, interfaces with available services - and conditions – e.g. policy, ethical, political, social, technological, economic, legal, ecological, etc.*
d. *The apparent ambiguity in the definition is deliberate. Both the system as a whole, and its parts, are "designed to interact with the operational environment in order to achieve an intended purpose…". The parts are also designed, or selected and adjusted, to relate to and interact with each other to create required system level properties.*
e. *Philosophically, some consider the engineered system itself to be the "whole" while others consider the system plus its environment to be the "whole" [Hall 1989]. These different mindsets can make a fundamental difference in the systems engineering methodology that will be most effective.*
f. *Practically, most engineered systems form part of one or more higher-level systems, and their parts may themselves be systems. Thus, systems engineering may be applied at multiple levels of an engineered system.*
g. *Engineered systems may be purely conceptual – e.g. software, or organisational structures and policies, or mathematical models.*
h. *An engineered system exists in two forms: first, as a conceptual system; comprising the model and other information that defines the intended system and its properties in its envisaged environment(s); and then, as one or more particular instances of the engineered system itself.*

The remainder of the document explains the proposed new definition of Systems Engineering.

RECOMMENDED DEFINITION OF SYSTEMS ENGINEERING

PRIOR INCOSE DEFINITION

Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems.

It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem:

- *Operations, Cost & Schedule, Performance,*
- *Manufacturing, Test, Training & Support,*
- *Disposal*

Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation.

Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

THE JOURNEY TO THE NEW DEFINITION

A paper offered to IS18 analysed the existing INCOSE definition of Systems Engineering in detail, discussed the paradigm shift now affecting Systems Engineering, and proposed a revision that was viewed at the time as the "minimum change" needed to address the various issues with the existing one.

One notable aspect of the paradigm shift is the need for the governing assumption about SE to move away from "SE takes charge" towards "SE facilitates effective collaboration". A second is the shift in focus from up-front definition of "controlled" systems operating in deterministic scenarios, towards "learning and evolving", and sometimes autonomous, systems operating in changing and non-deterministic environments; hence the emphasis on "purpose and success criteria", before "needs and functionality". A third is the need for SE to allow for market driven as well as customer driven development, so SE may be working with "anticipated" rather than "actual" customer needs and functionality. A fourth is a recognition that SE should be transdisciplinary (Rousseau et al, 2018) rather than merely interdisciplinary. The interim definition was as follows:

> *Systems Engineering is a transdisciplinary approach and means, based on systems principles and concepts, to enable the realization of successful whole-system solutions.*
>
> *It focuses on: establishing stakeholders' purpose and success criteria, and defining actual or anticipated customer needs and required functionality, early in the development cycle; establishing an appropriate lifecycle model and process approach considering the levels of complexity, uncertainty and change; documenting and modelling requirements for each phase of the endeavor, then proceeding with design synthesis and system validation; while considering the complete problem situation and all necessary enabling systems and services.*
>
> *Systems Engineering provides guidance and leadership to integrate all the disciplines and specialty groups into a team effort forming an appropriately structured development process that proceeds from concept to production to operation, evolution and eventual disposal.*
>
> *Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality solution that meets the needs of users and other stakeholders and is fit for the intended purpose in real-world operation.*

Subsequent discussion and further changes focused on a number of issues, including the following.

1. Change format from a "long definition" to a "short definition with explanatory notes"
2. Shift the emphasis in the explanatory notes from "documenting" to "modelling" and then "providing information".
3. Be much clearer in the explanatory notes about what SE involves, bringing in the concepts of the previous INCOSE fellows' Consensus "SIMILAR" model.
4. Add an emphasis on "coherence", of the endeavour and of the system, as one of the goals of SE.
5. A view that purpose is established by the SE process rather than identified by the stakeholders.

RECOMMENDED NEW DEFINITION OF SYSTEMS ENGINEERING

Systems Engineering is a transdisciplinary approach that applies systems principles and concepts to enable the successful realization and use of engineered systems and whole-system solutions.

Notes

1. *SE considers the business, technical, and societal needs of all the system's stakeholders, including customers, beneficiaries, users, owners, and relevant third parties, with the goal of providing a quality solution that is fit for its intended purpose in real-world operation.*

2. *Systems Engineering (SE) focuses on:*
    a. *establishing stakeholders' success criteria and concerns, and defining actual or anticipated customer needs and required functionality, early in the development cycle, and revising them as new information is gained and lessons are learned;*
    b. *investigating the solution space, proposing alternative solution concepts, weighing their value (viability, utility, benefit at cost) and selecting the optimal or most appropriate concept;*
    c. *architecting the high-level solution based on the selected concept;*
    d. *modelling the solution at each relevant phase of the endeavor, considering both normal and exceptional scenarios, and an appropriate diversity of viewpoints, in order to:*
        i. *establish required capability and performance;*
        ii. *make sure the solution will work as expected and required;*
        iii. *ensure the solution is resilient and can evolve if required to adapt to anticipated or possible changes in the user needs and operational environments;*
        iv. *provide ongoing prediction and assessment of system effectiveness and value;*
    e. *establishing an appropriate lifecycle model, and development and through-life system management processes, considering the levels of complexity, uncertainty and change;*
    f. *proceeding with detailed design synthesis, integration, and solution validation (ensuring the solution is fit for the intended purpose) while considering the complete problem, all necessary enabling systems and services, and end-of-life processes;*
    g. *providing the SE knowledge and information required by all stakeholder groups to ensure coherence of the whole endeavour - typically including operational concepts, business drivers, analyses and recommendations for decision support and the business case, architecture definition, organizational policies and processes, required properties and interfaces of the system and its elements, testing and evaluation criteria, analysis and interpretation of test and evaluation results, anticipated operational usage, and appropriate system configurations for different scenarios;*
    h. *periodically re-evaluating status, risks and opportunities, stakeholder feedback, and anticipated system effectiveness and value, and recommending any appropriate corrective, mitigation or recovery actions to ensure continuing system success.*

3. *SE provides guidance, facilitation and leadership to integrate all the disciplines and specialty groups into a team effort, forming an appropriately structured and coherent development process that proceeds from concept to production to operation, evolution and eventual disposal.*
    a. *SE is essentially collaborative in nature, working with and facilitating collaboration between all contributors to system success, recognizing the need to respect diverse of points of view;*
    b. *in some projects and in some organisations, SE may include a strong technical management and resource management component;*
    c. *in other projects and organisations, SE may have an almost entirely technical, advisory and "glue" role, if appropriate management and implementation structures already exist;*
    d. *SE may need to be applied at multiple levels of a complex project, programme or enterprise;*
    e. *the roles, responsibilities and accountabilities of SE, and how SE will interact with its internal and external stakeholders, should be documented in a management plan.*

4. *Fundamentally, the output of SE is information.*
    a. *SE synthesizes and provides the information required to describe the solution system, and to enable its successful realization and use (see 1.g above).*
    b. *Thus, SE is distinct from manufacturing, which produces product, and from operations, which uses the solution to deliver a service.*
    c. *SE is also distinct from individual engineering disciplines and specialisations.*
        i. *Engineering disciplines apply expertise in the use of particular technologies to provide efficient solutions to certain classes of problems.*
        ii. *Engineering specialisations apply specialist expertise to achieve particular whole-system properties such as safety, security, reliability, maintainability, and human factors.*
        iii. *SE applies expertise in the use of a transdisciplinary, domain-independent approach to provide effective solutions to complicated, complex and unprecedented problems, integrating the efforts of engineering and other disciplines and specialisations.*
        - *The difference between Complicated and Complex is discussed in, for example, Snowden and Boon (2007), and the INCOSE Complexity Primer (INCOSE, 2015).*
        - *Complicated systems can be viewed as knowable and deterministic, and once developed their configuration can be "frozen"; whereas complex systems are not fully knowable or deterministic, and continue to co-evolve with their environment throughout their lifecycle.*
        - *Most 20th century engineered systems were complicated; most 21st century engineered systems will be complex.*

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