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A fresh look at Systems Engineering – what is it, how should it work?

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Abstract. INCOSE's definition of SE was compared to the aspirations set out in SE Vision 2025 for SE as it ought to be to address modern challenges. Doing this led us to three fundamental realisations. First, while "20th century systems" were, for the most part, "deterministic" or nearly so, 21st century systems are on the other hand increasingly non-deterministic, adaptive or "evolutionary". Second, while "20th Century Systems Engineering Management" was implicitly based on a "command and control" paradigm, 21st Century Systems Engineering, to be successful, will usually need to use a more collaborative leadership paradigm. And third, that while 20th Century systems were largely "single systems", designed to "solve" specific problems, 21st Century systems are almost invariably networked, and are parts of complex extended enterprises with multiple, often conflicting, stakeholder objectives, that are intimately related to complex societal challenges. We used elements of Soft Systems Methodology (SSM) to understand the implication and consequences of the paradigm shift implied by these realisations. A revised strawman definition of Systems Engineering is offered for consideration by INCOSE, showing the changes that would be required to take these and related factors into account.

Introduction

Here is the current definition of Systems Engineering from the INCOSE website, and quoted in the INCOSE SE Handbook (INCOSE, 2015):

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*	*Test*	*Disposal*
Performance	*Training & Support*	*Manufacturing*	

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.

With the publication of its Vision 2025, INCOSE demonstrates that Systems Engineering is relevant, and can add value, to all branches of engineering, allowing interdependencies in complex systems to be better understood and collaboration to be more productive.

Driven by the need to make a step-change in the well-being of people worldwide, INCOSE's Vision 2025 (INCOSE 2014) sets out a vision for:

- expanding the application of systems engineering across industry domains;
- embracing and learning from the diversity of systems engineering approaches;
- applying systems engineering to help shape policy related to social and natural systems;
- expanding the theoretical foundation for systems engineering;
- advancing the tools and methods to address complexity;
- enhancing education and training to grow a systems engineering workforce that meets the increasing demand.

In view of these aspirations, and the rapidly changing nature of engineered systems, there is a need to revisit and refresh INCOSE's definition. The specific drivers for change include the following.

First, "20th century systems" were, for the most part, "deterministic" or nearly so, and their design paradigm sought to minimise or "conquer" complexity. 21st century systems are increasingly non-deterministic, adaptive or "evolutionary", and their design paradigm must be one that accepts, understands and seeks to manage complexity.

Second, 20th Century systems were largely "single systems", however complex, conceived as largely stand-alone systems and designed to "solve" specific problems. 21st Century systems are almost invariably networked, and parts of bigger systems. Many of these bigger systems are not single-purpose or single-agency but complex extended enterprises with multiple and diverse stakeholder objectives, often related to complex challenges such as achieving the Sustainable Development Goals (SDGs).

Third, many of the systems we are now concerned with include societal and naturally-occurring elements. Our understanding of "what a system is" has to expand to embrace these other system types – and these cannot be "controlled" in the way we expect to control purely technological systems, but can at best be understood and then influenced.

Finally, the ever widening international character of INCOSE's engagement indicates that more attention needs to be paid to cultural, environmental, and social factors, and how they influence and are influenced by the systems we are bringing into being.

Four consequences of these driving forces are that:

- uncertainty has become dominant in the landscape of systems engineering, and must be recognised and accepted in systems engineering decisions;
- customer needs and operational environments will change through the lifecycle, so engineered systems must now be designed to evolve throughout their life, often to be configured by the user rather than by the designer, and to be resilient to unforeseen and unpredictable shocks;
- successful design for resilience depends on effective collaboration and "requisite diversity" - of concepts, designers, users, and cultural and gender perspectives – and the makeup of systems engineering teams and the organizations they work in must reflect this requisite diversity, involving not only engineers and other experts, but also those who actually live and breathe the problems to be solved – in other words ensuring the key stakeholder "come into" the SE process;
- to be effective in the new collaborative landscape, systems engineers must focus on "enabling the success of others", achieving success through influence and collaboration, rather than seeking to impose a pre-defined SE process by "command and control" – and similarly, acting as interpreter and "glue" between different communities and speaking on behalf of others, so that stakeholders can continue to work as much as possible in their familiar language.

There is still a need to be able to develop robust, dependable technological "building blocks" for modern complex systems. This means that while INCOSE needs to expand its view of systems engineering as indicated above, it is equally important not to lose the excellent understanding we have built up over the years on how to engineer successful technological systems and products.

Below, we offer a new straw man definition for discussion, taking into account the issues we have identified during this work. Changes are highlighted in red.

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 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.

Structure of the rest of this paper

The rest of the paper elaborates the key points highlighted in the Executive Summary.

Our approach is as follows:

1. Describe the context for, and assumptions underpinning, our work, applying Checkland's CATWOE form of analysis first to the Fellows' Initiative to redefine SE, and then to Systems Engineering as a whole.
2. Summarise our appreciation of the upcoming paradigm shift in SE, which is described at length in INCOSE's 2025 vision.

3. present our conceptual model for Systems Engineering, discuss our deductions from this model, and describe SE in context.
4. Elaborate on our definition of the containing system, the "Context System for SE". Then we define SE in terms of its functions, inputs and outputs.
5. Identify the personal attributes of successful "system leaders", a key issue for the "collaborative" style of SE management which we believe will become increasingly prevalent.
6. Finally, in the "summary and conclusions", we explain why, in the light of our work, the proposed changes are appropriate, and offer the first draft of a revised definition for consideration.

Background and context for Fellows' Initiative and this paper

The Fellows' Initiative on System and SE Definition was launched at IS16 in Edinburgh, to consider strongly expressed views of some Fellows that the current INCOSE definition of SE may no longer be fit for purpose, in terms of current practice, and/or the future needs encapsulated in INCOSE's SE 2025 Vision. The INCOSE President and President Elect asked the Fellows to establish an initiative to consider the adequacy of INCOSE's current definition of Systems Engineering (SE), and to provide a White Paper on the topic. This paper is essentially an "academic version" of that white paper.

Previous and related work is described in preliminary outputs provided at IS17 in Adelaide, and in other papers offered to this symposium. The team's methodology included literature review, a series of team discussions, questionnaires issued to the Fellows and other members of the INCOSE community, and techniques from Checkland's Soft Systems Methodology (SSM). The initiative started by exploring the definition of "System" and worldviews on "system" held in the INCOSE community (Anonymous 1, 2017; Anonymous 2, 2017, Anonymous 3, 2018). The group then moved on to consider the definition(s) of Systems Engineering. A draft white paper issued to the Fellows just before the Adelaide International Symposium gave a brief overview of the work on "System", and then moved on to consider the key issues in the definition of "Systems Engineering". Feedback on the draft white paper led to a complete reappraisal of the approach to defining "Systems Engineering", going back to the basics of Soft Systems Methodology (SSM) to perform a CATWOE analysis to guide the next stage of the work. Further work on "re-visioning Systems Engineering for the 21st Century" is described in (Anonymous, 2018).

This section describes the assumptions underpinning the Fellows' Initiative and is based on the CATWOE (Customers, Actors, Transformation, Weltanschaaung or Worldview, Owners, Environment) style of analysis that forms part of Checkland's (1981) Soft Systems methodology (SSM). We look first at the Fellows' Initiative, and then at Systems Engineering as a whole.

CATWOE 1: Context and assumptions for the Fellows' Initiative

Customers. The immediate customers for the initiative are the INCOSE Board of Directors (BoD) and leadership, including the CAB (Corporate Advisory Board). The wider intended customer base includes all who practice or have an interest in Systems, Systems Engineering, and using a Systems Approach.

Actors. The actors are the team of authors who create this white paper.

Owners. The owners are the INCOSE President and President Elect.

Transformation. There is a need for transformation of the definition of Systems Engineering, as shown in Table 1.

Table 1: Summary of needed transformation in definition of SE

From the present paradigm	**To** the future paradigm
of robust, dependable, mainly-technological, “deterministic systems”	of resilient, adaptive “evolutionary systems” and systems-of-systems, encompassing products, services and enterprises, integrating technological, social and environmental elements
implicitly, a command and control view of how SE works	explicitly, a collaborative view of how SE works

Weltanschaauung. The need for the transformation results from an emerging worldview within INCOSE and elsewhere that includes the following key assumptions and beliefs.

SE will become increasingly relevant to a broad range of application domains, well beyond aerospace and defence, to meet society’s growing quest for sustainable system solutions to provision of fundamental needs. Systems Engineering must address systems of increasing complexity that include emergent behaviours associated with system interdependence and societal and environmental interactions. The skills involved in systems engineering will broaden to address the increasing complexity and diversity of future systems.

SE is essentially collaborative, and must increasingly operate, and where appropriate lead, by respect and influence rather than by trying to impose a “command and control” style of management.

It is important in this exercise to identify what is unique about SE and why SE is different from PM and discipline engineering.

There is a need to increase the “aperture” of systems engineers and systems engineering to increase awareness of the wider effects of their actions and their responsibility to minimise unintended consequences including harm to wider society, the natural environment and the planet as a whole.

Environment. Our view of the **environment** for the initiative includes the following key drivers:

- a rapid change in the nature of the systems society depends on (including radically increased software content and networked connectivity);
- increasing problems in these systems with sustainability, unforeseen emergence, vulnerability to cyber attacks and climatic disruption;
- evolution of systems (technological and societal) in uncontrolled and ungoverned ways (sometimes good sometimes bad);
- increasing human pressures on planetary resources.
- a lack of clarity on how Systems Engineering (SE) as an “interdisciplinary approach and means” is supposed to, or can, fit into wider organisations concerned with systems through their lifecycle.

CATWOE 2: Context and Assumptions for Systems Engineering

We now apply the CATWOE analysis method to Systems Engineering as a whole.

Customers. The customers for Systems Engineering (SE) are:

- Sponsors and problem owners, who want a new system or an improvement to an existing one;
- All participants in the relevant Context System for SE, which we define shortly;
- Society at large.

Actors. The actors in SE are SE practitioners, in collaboration with relevant practitioners with domain, discipline expertise, as well as required cognitive and behavioural skills.

Transformation. The **transformation** performed by SE is:

from an unstructured problem or opportunity in the context system;

to a comprehensive approach to enabling realization of a whole system solution, including

1. a structured definition of:
    a. the problem or opportunity;
    b. stakeholder interests, purpose(s) and success criteria;
    c. an effective and fit-for-purpose system solution;
    d. and an effective and efficient process for developing, deploying, supporting, operating and retiring it, and for assessing its effectiveness and fitness for purpose;

2. ongoing and regularly updated estimate of
    a. system effectiveness and fitness for purpose,
    b. and the potential for, and risk of, adverse unintended consequences for stakeholders, wider society and the environment;

3. enabling activities to ensure the success of both the system, and the context system in which SE operates.

Weltanschaaung. The Worldview, or Weltanschaaung, for Systems Engineering (or at least our view of it) is as follows.

The essence of SE is its holistic (whole system, whole lifecycle) and interdisciplinary nature. Key skills for doing SE are systems analysis and systems thinking. But system success depends on *people with a wide range of skills* **working together**.

Since emergent properties are a defining characteristic of systems (Anonymous 1 & 2, 2017), it follows that a defining characteristic of systems engineering is the manipulation of the relationships, interfaces and interactions between the parts of the system to obtain the desired system-level emergent properties and mitigate undesired properties.

The overall goal of SE is to enable success of both the system, and the "Context System for SE", while avoiding deleterious and harmful unintended consequences for stakeholders, wider society and the environment. SE depends on successful collaboration between individuals with

- systems skills,
- a wide range of domain and discipline skills relevant to the problem space and range of solution options,
- cognitive, behavioural and psychological skills and cultural understanding applied both to SE in its business or other organizational context, and to the system of interest in its operational context.

The exercise of systems skills by SE practitioners involves both systemic (big picture, unbounded) and systematic (attention to detail and completeness) skills. Often the system of interest involves complex integration of heterogeneous technologies, in which case a key aspect of SE is integration of the various technologies with each other and with the socio-technical and natural environments.

SE can be viewed as what Checkland (1981) defines as a "Human Activity System" (HAS), and as a "holon", a systems thinking concept defined as both a whole system in its own right, and part of a wider system, which in this case is the Context System for SE.

Owners. The owners of SE are the sponsors of the system, or the "problem owner" of the problematic situation that needs to be addressed.

Environment. The wider environment within which SE operates is the "***Context System for SE***". We define this as a loosely coupled network of organisations comprising all entities involved in creating, operating, supporting, evolving, and retiring the system of interest throughout its lifecycle.

SE may operate as a distinct entity within this environment, or be distributed throughout the constituent organisations. The INCOSE SE 2025 Vision observes that hand-offs across organisational, commercial and lifecycle phase boundaries may cause significant delays, errors, misunderstandings and information loss.

An opportunity in the environment for SE is increasing interest in the concept of **trans-**disciplinarity, as opposed to **inter-**disciplinarity. From a research perspective (Rousseau, 2015) *transdisciplinarity springs from insights about patterns than emerge only by looking across disciplines, so tell us something about the fundamental nature of the world; hence it is a powerful additional problem solving technique. GSTD [General Systems TransDisciplinarity] is about systems and is general, so it applies always and everywhere.*

Translating this thinking into a Systems Engineering context, "not just having engineers involved" is the key feature of Transdisciplinarity that makes it different (and better than) multi-disciplinary and cross-disciplinary approaches, especially for complex socio-technical challenges.

Transdisciplinarity connotes a strategy that crosses many disciplinary boundaries to create a holistic approach. For example, in defence and aerospace systems engineering, it is common practice to involve both operational users and specialists in human factors and psychology when formulating operational concepts, user requirements, and human-machine interface designs. In general, a transdisciplinary approach enables *inputs and participation across technical and non-technical stakeholder communities* and facilitates a systemic way of addressing a challenge.

Transdisciplinarity emphasises the benefits of bringing in people who actually live and breathe the problems trying to be solved, such as ordinary people, local politicians, businesses, social groups, etc. – in other words, ensuring that the key stakeholders come "into" the SE process. But it also entails having those outsider stakeholders help shape the process to be used for problem and solution space definition. This is because people bring their worldviews with them when they start examining what they think the problem really is, which carries over when you start trying to solve the "problems" you identified. You don't just invite them to design reviews to see if they concur or not. This is an example of how a system, in this case Systems Engineering itself, both changes and is changed by its environment.

Such a development would provide a Systems Engineering meta-framework for integrating all the different discipline activities – technical and non-technical, from within and far beyond engineering - in a systems context.

The up-coming paradigm shift in Systems Engineering

This section highlights the paradigm shift that is happening in Systems Engineering. This paradigm shift is the justification for re-visiting the definition.

It is presented as a summary table contrasting several different perspectives on where SE has come "from" and where it is going "to".

Table 2: Summary of upcoming Paradigm Shift in SE

From	To
“Ballistic” SE – System trajectory set by initial conditions established at start of lifecycle	“Goal-oriented” SE – System trajectory monitored and adjusted to achieve and maintain fitness for purpose throughout the system lifecycle
Complexity feared and minimised	Complexity understood and managed
“Deterministic” systems	“Evolutionary” systems
SE defined as technical and management process activities associated with (mainly technological) system development and whole-lifecycle support to operations	SE defined as a collaboration between people with a variety of competencies needed for whole-system whole-lifecycle success, including o **systemic** and **systematic** “SE” knowledge and leadership o domain and discipline knowledge (societal and environmental as well as technical) relevant to the problem space and solution options o cognitive, behavioural and psychological skills applied both to SE in its business context, and to the system of interest in its operational context
SE defined rather in a vacuum – vague about the context in which it operates	SE defined as a “human activity system” operating within the “Context System for SE” – specific about the context in which it operates through the whole system lifecycle

Focus of SE is:
o interdisciplinary
o to engineer dependable, robust, pseudo-deterministic, mainly technological systems
o requirements and operational concepts that
    o can be established early in the lifecycle
    o are not expected to change (much) through life
	Focus of SE is opened out:
	o transdisciplinary
	o to address resilient, adaptive systems and systems-of-systems that may be in a state of continual evolution (at least their operational environment, and probably the system as well),
	o systems of interest may be autonomous, possibly involving Artificial Intelligence, probably involving environmental aspects, and certainly involving social aspects as well as engineering and technology.
	o to address societal grand challenges related inter alia to the Sustainable Development Goals (SDGs)
	o Such systems will still need dependable robust technological building blocks (which is why we say the focus “opens out” rather than “shifts”).

Conceptual Model for Systems Engineering

Part of Checkland’s (1981) Soft Systems Methodology involves the construction of a conceptual model of the system under consideration. This conceptual model can take many forms. We chose to show the interaction between “SE” and “SOI” (system of interest, or in other words the system being engineered), in the wider context of each.

Usually, models of SE show that the SoI exists in a wider context or containing system, which is sometimes referred to as the **context system**. Far fewer models of SE give equal (or indeed any) prominence to the wider context system for SE. SE is usually either conceptualised in a vacuum, or assumed to be the sole organising and governance principle for the entire set of organisations involved with a system. Usually nowadays neither of these applies – SE is practiced within a wider context with multiple priorities and multiple cultures.

In view of this we have concentrated in the following sections on making explicit the interfaces, interactions, relationships and interdependencies between SE (which, following Checkland, we view as an abstract “human Activity System”) and the other elements of its environment.

SE in Context

There was some debate in the response to our first Draft White Paper (INCOSE Fellows’ Initiative Team, 2017) about whether SE can be regarded as a system. In terms of the definition of *system* we have adopted for our own work and recommended to INCOSE (Sillitto et al, 2017; Dori & Sillitto,

2017) it most certainly is. We can therefore apply what we know about designing systems in general, and Checkland's advice on Human Activity Systems in particular, to our work.

Identifying SE as a system leads to the appreciation that SE should logically also exist in a wider containing system, the **context system for SE**. Thus, we have a symmetrical conceptual structure as shown in Fig 1.

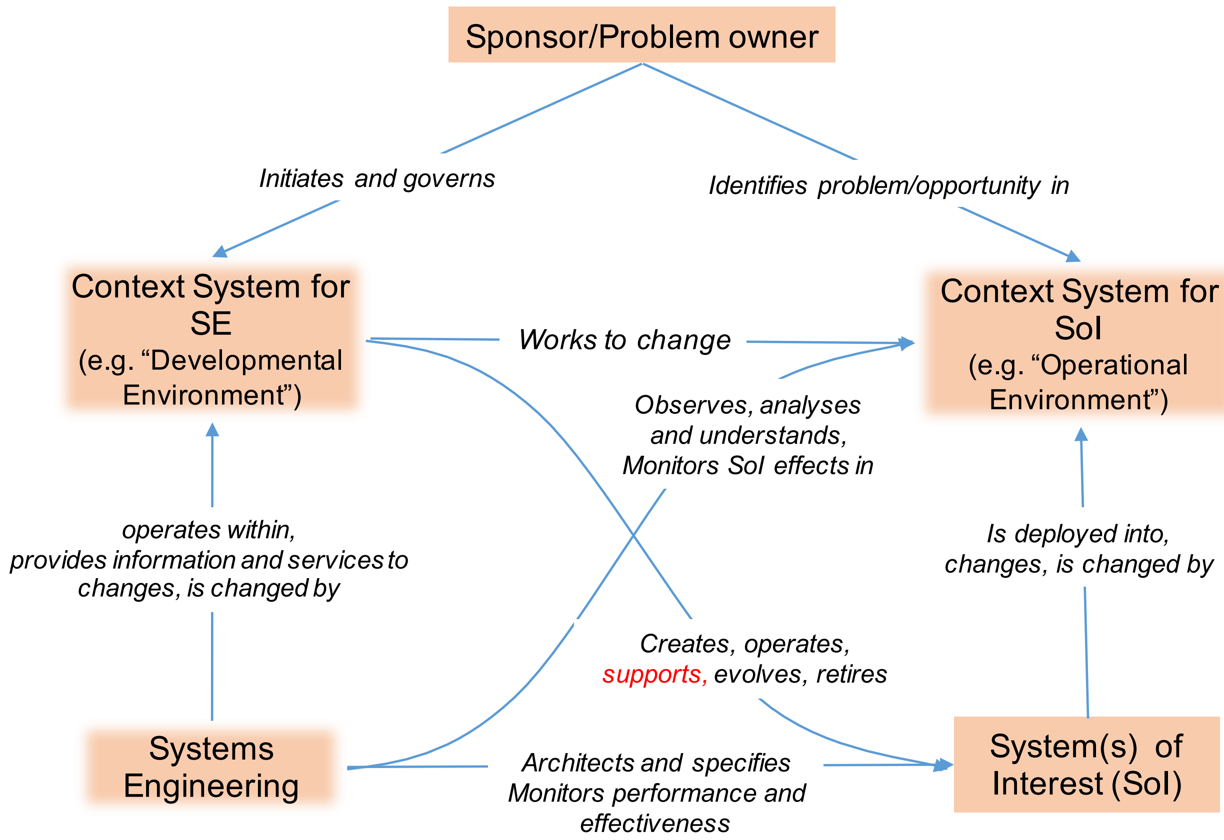

Figure 1. Conceptual (or "logical") model for SE in context

This is a conceptual model to allow clear thinking and analysis, and its structure won't necessarily match any real organization chart. The roles and responsibilities associated with each conceptual box in the diagram may be allocated across multiple individuals and organisations, and conversely, one organization or individual might be involved in several or all of the conceptual boxes.

In this model, a sponsor or problem owner identifies a problem or opportunity in an operational environment, which will become the "context system" for the SoI (System of Interest).

The sponsor or problem owner initiates and governs the Context System for the Systems Engineering activity associated with the SoI.

The **Context System for SE** works to achieve a beneficial change in the Operational Environment. If this beneficial change is believed to require a new system, or an improvement to an existing one, then the Systems Engineering activity is initiated.

The primary goal of SE is to architect and specify the system of interest, (or the changes to it in the case of an existing system) and then to monitor performance, effectiveness and fitness for purpose during development and operation.

In order to be able to do this, SE first observes, analyses and understands the problem or opportunity in the **context system**, so as to

- frame the problem, and
- establish the purpose and required effects of the system of interest.

Once the **system of interest** has been made or modified, and put into its **context system**, SE monitors its actual effect on the context system in operation, and determines any necessary changes to the system of interest, or to the way it is used, to achieve the desired effect and avoid or mitigate adverse unintended consequences.

SE exists within its own context system, the Context System for SE, which, by analogy with the notion of "operational environment" for the SoI, we can think of as a "developmental environment" in which the SE "system" operates. This "Context System for SE" or "developmental environment" typically involves several or many collaborating (and competing) organisations.

SE interacts with, and its outputs and services are used by, various other entities in the Context System for SE. SE may be done by a distinct entity or distributed throughout the various organisations involved.

Both the SoI, and SE, are open systems. This mean that when they are deployed they both change and are changed by their respective context systems. Often, the context system will react against a new system that is deployed into it. Biological systems create antibodies to fight infection. Armies develop new tactics and new weapons to counter new enemy systems and tactics. Organisations often exhibit an immune response when injected with a new "system", such as SE. A key aspect of successful deployment of SE is to anticipate and avoid triggering the organisational immune response. This is why we attach so much importance to changing SE management from an implicitly "command and control" paradigm to an explicitly collaborative one, leading through influence, respect and collaboration rather than managing by "command and control".

"SE in context" is a holon in a yet wider context

The "system of systems" shown in Fig 1 can be thought of as a "holon", both a whole system in its own right, and part of a wider system. The boundary of the wider system may be unclear. To avoid unproductive and unnecessary argument, we assume the containing system for the "system of systems" holon shown in Fig 1 is our planet (Fig 2).

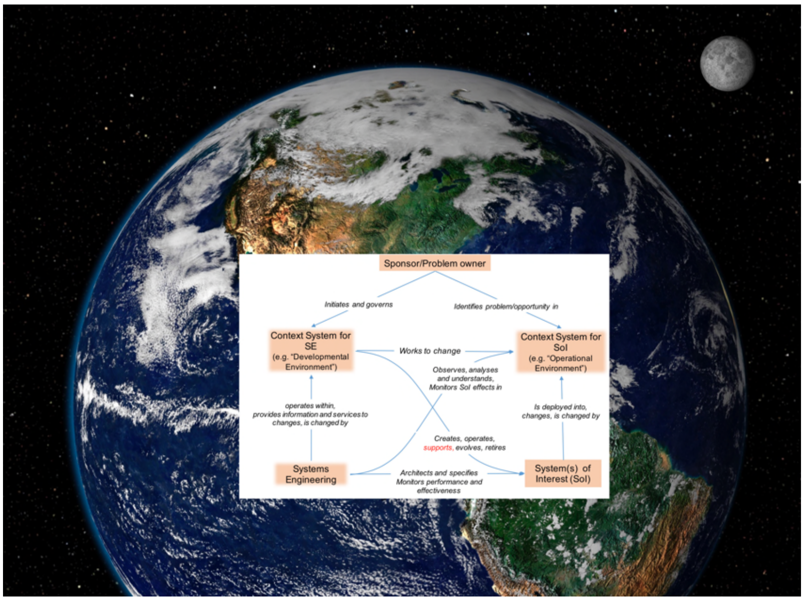

Fig 2: SE in context in context

Some additional points to note on this model are as follows.

- in a formal or conceptual sense, this model shows the classic separation between “design-and-build” and “operate-and-support” environments; but the developmental environment is often contained within, rather than being distinct from, the operational environment;
- some of the stakeholders and actors in the “Context System for SE” also work in the operational environment;
- the operational environment includes or is linked to threat and resource environments, as described by Hitchins (2007).

What is the Context System for SE?

The “Context System for SE” is the loosely coupled network of organisations that collectively manages a particular system of interest, or a related set of systems of interest, through the whole system lifecycle. Thus, it:

- seeks to create beneficial change in the operational environment on behalf of a sponsor or “problem owner” - for which purpose, when necessary, it creates, operates, evolves, supports and retires the system(s) of interest;
- acts as the “context system” for the Systems Engineering “human activity system” concerned with the particular system(s) of interest;
- provides the context and constraints within which the SE for a particular system(s) of interest takes place.

Thus, SE is viewed as a whole system in its own right, and also forms part of a larger system, in this case the whole “Context System for SE” - the business or other organisational environment in which SE takes place.

The SE Human Activity System is typically partitioned among the organisations participating in the Context System for SE. This may result in extra complexity - for example by imposition of arbitrary commercial and life-cycle phase boundaries, as well as any natural partitioning to match the logical structure and hierarchical layering of the system of interest. The INCOSE SE 2025 Vision (INCOSE 2014) points out that hand-offs across these boundaries may cause significant delays, errors, misunderstandings and information loss.

Note that the triad of System of Interest, the Context System for the SoI, and the Context System for SE, is related to, but does not exactly correspond with, Schindel’s (2016) “System 1, System 2 and System 3” triad. Our SoI is Schindel’s System 1, while our “context system for SE” seems to be both of Schindel’s systems 2 and 3.

Characteristics and interfaces of Systems Engineering

To define what systems engineering is and does, we follow normal systems engineering practice and attempt to identify its boundaries, functions and input-output characteristics.

Services required by SE

SE requires services from various other entities in the Context System for SE:

- Resources, facilities, budget approvals, target timescales, access to relevant stakeholders and decision makers...
- A governance framework that ensures SE outputs are available to relevant stakeholders and are properly exploited...

- Co-ordination of the SE process framework and information framework with, e.g., overarching quality system, contracting frameworks, PLM and general business software, information governance…

Services offered by SE

SE offers information and services to other entities in the Context System for SE, including:

"**Problem framing**" – a framing or structuring of the problem or opportunity in context - including rate and predictability (or not) of change;

Clarify and formalise stakeholder **purpose** and **success criteria (preferably in terms of outcomes not outputs);**

Solution options, with predicted effectiveness, fitness for purpose, cost and risk, analysis of alternatives – and rate of change of relevant factors in solution space;

A Process Framework, a description of the whole-lifecycle processes necessary for system success, which need to be included in the management processes of the Context System for SE (e.g. the ISO/IEC 15288 System Lifecycle Processes standard describes a set of lifecycle processes considered necessary for system success, which it advises should be incorporated into the overarching organizational process set);

An Information Framework, a definition of the overall information architecture and associated governance required to capture, manage, and maintain the information generated by the SE activities, and distribute that information to the people who need it (SE activities produce information describing the system, the envisaged operational environment, use cases, options, models, simulation and test data, decisions and supporting rationale, etc);

A Solution Framework, a structured definition of the system to be designed and built, including documents or models or both, which evolves through various stages including as-imagined, as-specified, as-architected, as-designed, as-tested, as-delivered, as-operated, as-updated, as-retired, as-disposed-of; and should cover functional, physical, behavioural, performance and lifecycle aspects;

Evidence of the system's predicted and actual performance, effectiveness and fitness for purpose, unintended consequences;

Evidenced change proposals – proposals to improve system effectiveness, with supporting evidence of feasibility and predicted/demonstrated effectiveness;

Co-ordination and Leadership – SE's purpose is to enable system success - and in a complex environment, this is often best achieved by influence, not control. A key element of systems co-ordination and leadership is to facilitate shared model building so that both informal and formal models of the solution are shared, understood and "owned" by the whole team.

Systems Leadership skills

We have already stated that SE is a collaboration between people with competence in SE, and in the domains and disciplines relevant to the operational environment and to the SoI solution concept(s*)*, and with socio-technical skills – cognitive, behavioural, psychological - applied both to the systems engineering activities and to the system of interest.

The landscape for Systems Engineering is undergoing a set of simultaneous changes, which taken together amount to a Kuhnian paradigm shift (Kuhn, 1970), in the **environment** for engineered systems, the **nature** of such systems, and the **way we need to work** to create and evolve them. Recognising the need for leadership that can enable teams and organisations to navigate this changing landscape successfully, INCOSE has developed a Technical Leadership Model (Godfrey, 2016) which integrates the attributes believed to characterise the attributes of a successful systems engineering leader.

These naturally organised themselves into six behaviours defined as:

- Holds the Vision;
- Thinks Strategically;
- Fosters Collaboration;
- Communicates Effectively;
- Enables others to be successful;
- Demonstrates Emotional Intelligence.

The best future systems engineers will develop and exercise these leadership skills at all stages of their careers and at all levels of responsibility alongside their systemic and systematic "systems engineering" skills.

Summary and Conclusions

This document reviewed the reasons for changing the INCOSE definition for systems engineering and provided some pointers for the direction of possible change. In this summary and conclusions section, we tie the discussion and these pointers to the affected parts of the current INCOSE definition of SE.

Summary: Issues with Current INCOSE Definition of SE

Issues with the current definition, and possible changes to deal with them, are listed in Table 3.

Table 3: Where do we need to change the current definition of SE?

Current text	**Suggested changes**
Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems.	"Interdisciplinary" to "transdisciplinary" Add, after "means", "based on systems principles" Change "successful systems" to "successful whole-system solution".
It focuses on - defining customer needs and required functionality early in the development cycle, documenting requirements,	add, or replace existing text with, "establishing purpose and success criteria, and…" consider implication of and for evolutionary systems, where required functionality may change leading to evolution of the functionality during operations customer needs may be actual, for customer funded development, or anticipated, for self funded.
then proceeding with design synthesis and system validation	do we need to add considerations of fitness for purpose?
*while considering the complete problem**:** Operations, Cost & Schedule, Performance, Training & Support, Test, Disposal, Manufacturing,*	this should be wider, for example "all enabling systems and services required at all stages of the lifecycle."

Current text	Suggested changes
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.	This language has strong suggestions of a "command and control" approach to SE management, which is not acceptable (or not practical politics) in many industries, countries and cultures that are adopting SE. Need to add a recognition of the frequent need for a "leadership by influence" style. "Proceeds from concept to production to operation" is specific to products, and implies a one-shot waterfall lifecycle. This needs to be generalised, to cater for the "Devops" technique used in many software intensive systems, and also to cater for evolutionary systems where some or many of the requirements are only discovered when the first version of the system becomes operational. It should also consider product evolution and upgrade, and eventual disposal.
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.	This should have wider scope and perhaps reference fitness for purpose. Replace "quality product" with "quality solution" Add "and is fit for the intended purpose in real-world operation" after "user needs".

Conclusion: Straw Man Updated Definition

These changes, if adopted, would lead to something like the following straw man revised definition (proposed changes in red):

Systems Engineering is a transdisciplinary approach and means, based on systems principles and concepts, to enable the successful realization, use and retiral of engineered systems.

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 modeling requirements and solution architecture for each phase of the endeavour*
- *proceeding with design synthesis and system validation*
- *while considering the complete problem and all necessary enabling systems and services.*

Systems Engineering provides facilitation, 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, and avoids or minimizes adverse unintended consequences.

Further work is required on this strawman. We need to make sure the language does not come over as too defence-focused. We need to ensure that the operating styles in different markets are taken into account: for example in many consumer product sectors, product requirements are determined more by competitive pressure and by benchmarking against competing products and market trends, than by what the customers say they need. In many industries the Systems Engineers are not necessarily "in charge", but exercise a form of leadership by providing interpretation, collaboration and cohesion.

There are key debating points around whether it is desirable and realistic for the definition to include notions of "do no harm", and "no unauthorised response to unauthorised stimuli".

It goes without saying (or maybe it doesn't) that we think the eventual agreed definition should be shorter – or if not, that there should be a short, concise, punchy version for general use. These changes will be discussed further and more widely. This paper is part of the engagement mechanism to promote that discussion. An updated proposal will be offered for discussion at the Symposium itself.

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Biography

Hillary Sillitto held senior systems engineering and architecting positions in Thales and the UK MoD, and is now pursuing a variety of academic and professional interests. His book "Architecting systems – concepts, principles and practice" was published in October 2014. He contributed to the INCOSE SE Handbook and the SEBOK. He is an INCOSE Fellow, and Omega Alpha Association member.

James Martin is an enterprise architect and systems engineer affiliated with The Aerospace Corporation. He was a key author for the SE Body of Knowledge (SEBOK), led the working group developing ANSI/EIA 632, and the INCOSE Standards Technical Committee. He previously worked for Raytheon Systems Company and AT&T Bell Labs. His book, Systems Engineering Guidebook, was published by CRC Press. Dr. Martin is an INCOSE Fellow and received the Founders Award.

Dorothy McKinney is an INCOSE Fellow, serving on the INCOSE Definition Team. She has over 45 years of aerospace and research experience, working over 34 years at Lockheed Martin and heritage companies. She served as an adjunct professor at San Jose and Portland State Universities. She now heads ConsideredThoughtfully Inc., providing online mentoring for professionals.

Professor Dov Dori heads the Enterprise System Modeling Laboratory at the Faculty of Industrial Engineering and Management, Technion, Israel. He is Fellow of IEEE, INCOSE, and IAPR and a Visiting Professor at MIT. His research interests include MBSE and conceptual modeling of complex systems, and systems biology. He invented and developed Object-Process Methodology (OPM), adopted as ISO 19450, authored over 300 publications and mentored over 50 graduate students.

Regina M. Griego, Ph.D. is an independent Systems Consultant and retired as a Distinguished R&D Systems Engineer at Sandia National Laboratories after 20 years of service. She has over 30 years of experience leading multi-agency and multidisciplinary teams in various domains to deliver systems and develop organizational capability. She is a teacher, mentor, and coach and recognized for her research and ability to elicit a common conceptual basis for realizing solutions. Regina is an INCOSE Fellow, past Technical Director, and the Enchantment Chapter Founding President.

Eileen P. Arnold**,** Fellow of INCOSE, ESEP, and PMI PMP worked 35+ years as a system engineer in weapons systems and commercial and Business/Regional aircraft. She currently works as the co-founder of a Start Up company, ConsideredThoughtfully, Inc., developing virtual professional mentoring applications. She received the MFESTS Charles W. Britzius Distinguished Engineer Award. She has been an active INCOSE and IEEE volunteer and author since 1996.

Patrick Godfrey has been civil engineering practitioner for 50 years. He was a Director of Halcrow for 30 years, Professor of Engineering Systems at the University of Bristol for 10, and is now an Emeritus Professor. He believes systems thinking and learning skills are two sides of the same coin required to deliver Vision 2025. He is a Fellow of the Royal Academy of Engineering, INCOSE, the Institution of Civil Engineers, the Energy Institute; and Honorary Fellow of the Institute of Actuaries.

Daniel Krob is currently Institute Professor at Ecole Polytechnique and chairman of CESAMES, the French leading company in systems architecting and engineering. He authored more than 100 papers, 6 books and 3 patents in areas including combinatorics, computer science, communications and systems modeling. He managed many training, consulting and transformation missions in systems engineering within major industries among aerospace, automotive, bank, energy and high tech.

Scott Jackson is an independent consultant and researcher. His book *Systems Engineering for Commercial Aircraft* (2nd Edition) was published by Ashgate Ltd in the UK in 2015 (available in both English and Chinese). He also wrote *Architecting Resilient Systems: Accident Avoidance, Survival, and Recovery from Disruptions*, (Wiley 2010). He taught graduate level courses in systems engineering at USC, and now assists aircraft companies around the world in systems engineering.