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Systems Engineering and System Definitions

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EXECUTIVE SUMMARY

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.

This document presents the final proposals from the initiative. It takes into account the extensive comments received during the review of the previous draft in September 2018. The review was open to all INCOSE members, and attracted over 350 individual comments and suggestions.

The three key recommendations – for definitions of systems engineering, engineered system, and a general definition of system - are presented below, with a very brief contextual explanation. After the table of contents, the main body of this document provides more explanation of these definitions, and also defines other specific system types and categories that are important for the systems engineering community.

Systems Engineering is *a **transdisciplinary** and **integrative** approach to enable the successful realization, use, and retirement of **engineered systems**, using **systems principles and concepts**, and scientific, technological, and management methods.*

We use the terms "engineering" and "engineered" in their **widest sense**: "the action of working artfully to bring something about". "**Engineered systems**" may be composed of any or all of people, products, services, information, processes, and natural elements.

*An **engineered system** is a system designed or adapted to interact with an anticipated operational environment to achieve one or more intended purposes while complying with applicable constraints.*

Thus, an "engineered system" is a system – not necessarily a technological one - which has been or will be "systems engineered" for a purpose.

Finally, a very general and inclusive definition of "system" is provided:

*A **system** is an arrangement of parts or elements that together exhibit behavior or meaning that the individual constituents do not.*

Systems can be either physical or conceptual, or a combination of both. Systems in the physical universe are composed of matter and energy, may embody information encoded in matter-energy carriers, and exhibit observable behavior. Conceptual systems are abstract systems of pure information, and do not directly exhibit behavior, but exhibit "meaning". In both cases, the system's properties (as a whole) result, or emerge from:

- the parts or elements and their individual properties; AND
- the relationships and interactions between and among the parts, the system and its environment.

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SYSTEMS ENGINEERING

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Systems Engineering focuses on:

- establishing, balancing and integrating stakeholders' goals, purpose and success criteria, and defining actual or anticipated customer needs, operational concept and required functionality, starting early in the development cycle;
- establishing an appropriate life cycle model, process approach and governance structures, considering the levels of complexity, uncertainty, change, and variety;
- generating and evaluating alternative solution concepts and architectures;
- baselining and modelling requirements and selected solution architecture for each phase of the endeavor;
- performing design synthesis and system verification and validation;
- while considering both the problem and solution domains, taking into account necessary enabling systems and services, identifying the role that the parts and the relationships between the parts play with respect to the overall behavior and performance of the system, and determining how to balance all of these factors to achieve a satisfactory outcome.

Systems Engineering provides facilitation, guidance and leadership to integrate the relevant disciplines and specialty groups into a cohesive effort, forming an appropriately structured development process that proceeds from concept to production, operation, evolution and eventual disposal.

Systems Engineering considers both the business and the technical needs of customers with the goal of providing a quality solution that meets the needs of users and other stakeholders, is fit for the intended purpose in real-world operation, and avoids or minimizes adverse unintended consequences.

The goal of all Systems Engineering activities is to manage risk, including the risk of not delivering what the customer wants and needs, the risk of late delivery, the risk of excess cost, and the risk of negative unintended consequences. One measure of utility of Systems Engineering activities is the degree to which such risk is reduced. Conversely, a measure of acceptability of absence of a System Engineering activity is the level of excess risk incurred as a result.

TRANSDISCIPLINARY APPROACH

Transdisciplinarity is described in Wikipedia as an approach which "crosses many disciplinary boundaries to create a holistic approach." This emphasis on a holistic approach distinguishes it from cross-disciplinary, which focuses mainly on working across multiple disciplines while allowing each discipline to apply their own methods and approaches. Systems engineering is simultaneously cross-disciplinary and transdisciplinary. (The cross-disciplinary aspect is discussed in the next section on the Integrative Approach.)

The transdisciplinary approach originated in the social sciences. It “transcends” all of the disciplines involved, and organizes the effort around common purpose, shared understanding and “learning together” in the context of real-world problems or themes. It is usable at any level, from complex to simple, from global to personal. A transdisciplinary approach is needed when the problem cannot readily be “solved” and the best that can likely be achieved is instead a “resolution.” The participants in the endeavor need to “transcend” their particular disciplinary approach to instead come to some overall useful compromise or synergistic understanding that their disciplines cannot come to on their own (even when working together in a normal integrative approach with other disciplines).

INTEGRATIVE APPROACH

The integrative approach has long been used in systems engineering and usually involves either interdisciplinary (e.g.. integrated product teams) or multi-disciplinary (e.g.. joint technical reviews) methods. The integrative approach by itself can be adequate where the situation is not overly complex and there are smaller numbers of stakeholders potentially impacted. The integrative approach can be used when dealing with a highly precedented situation that has been encountered before and a path to the solution can be readily identified and understood (albeit there will still be many challenges along the way, technical and otherwise). The integrative approach includes the traditional multi-disciplinary and inter-disciplinary approaches commonly used in systems engineering practice. The transdisciplinary approach may be needed in unprecedented situations or where there is a significant degree of complexity involved. See Madni (2018).

SYSTEMS PRINCIPLES AND CONCEPTS

Systems principles and concepts are the ways that systems thinking and the systems sciences infuse systems engineering. Examples of some of the principles, concepts and supporting tools are: mental models, system archetypes, holistic thinking, separation of concerns, abstraction, modularity and encapsulation, causal loop diagrams, and systems mapping. (The Systems Engineering Body of Knowledge describes many of these, and more, at https://www.sebokwiki.org/wiki/Principles_of_Systems_Thinking).

ENGINEERING AND ENGINEERED

Both ancient and modern definitions of Engineering allow for the wide interpretation intended here. For example, Google dictionary defines Engineering in two ways:

1. the branch of science and technology concerned with the design, building, and use of engines, machines, and structures.
2. the action of working artfully to bring something about.

And Wikipedia:

- Engineering is the creative application of science, mathematical methods, and empirical evidence to the innovation, design, construction, operation and maintenance of structures, machines, materials, devices, systems, processes, and organizations.
- The term engineering is derived from the Latin ingenium, meaning “cleverness” and ingeniare, meaning “to contrive, devise”.

ENGINEERED SYSTEMS

An **engineered system** *is a system designed or adapted to interact with an anticipated operational environment to achieve one or more intended purposes while complying with applicable constraints.*

The following may be useful as a working definition that focuses on what it "is": *An engineered system is a composite of people, products, services, information, and processes (and possibly natural components) that provides a capability that satisfies a stated customer need or objective.*

Thus, an "engineered system" is a system – not necessarily a technological one - which has been or will be "systems engineered" for a purpose. Note that the required behavior of such a system might be achieved by influence and self-organization, rather than by top-down direction.

The people component can be individuals, roles, organizations, organizational units, governance structures, etc. The products component can be hardware, software, firmware, data, facilities, etc. The services component can be business services, information services, application services, infrastructure services, etc. The information component can be individual information items, information categories, information structures, documentation, knowledge elements, etc. The processes component can be procedures, methods, techniques, work instructions, policies, directives, etc. Capability is an ability to do something in the anticipated operational environment.

The category of "engineered system" includes the sub-categories of products, services and enterprises. Services and enterprises usually depend on technological products but are essentially forms of socio-technical systems.

ENTERPRISES

"Enterprise" is intended to mean a large undertaking, especially one of large scope, complication and risk – "a complex web of interactions distributed across geography and time" (Rebovitch & White, 2011). We do not just mean a large organization, since an enterprise often has multiple organizations that participate in the enterprise to the extent that each organization will derive some benefit from its participation. An enterprise is an endeavor usually requiring special initiative and boldness. Not all large activities are enterprises since their size does not necessarily entail taking large risk or dealing with a complicated situation.

SERVICES

"Service" is intended to mean actions taken to satisfy needs of individuals or organizations. The term service initially was used in the last century to describe actions which involved no tangible products at all. Early in this century (per Wikipedia at https://en.wikipedia.org/wiki/Managed_services) "managed services" emerged as a business model. The "service economy" (per Wikipedia at https://en.wikipedia.org/wiki/Service_economy) has resulted in an evolution in the meaning ascribed to "service": "The old dichotomy between product and service has been replaced by a service-product continuum. Many products are being transformed into services. The Cambridge dictionary at https://dictionary.cambridge.org/us/dictionary/english/service says service is "work done or help provided, especially for the public or for a person or an organization."

DEFINITION OF SYSTEM: GENERAL CASE

A **system** *is an arrangement of parts or elements that together exhibit behavior or meaning that the individual constituents do not.*

“Parts” is the more general term, going back to Aristotle’s phrase “the whole is more than the sum of the parts”. “Elements” has become established as the preferred term in recent systems engineering usage. The two terms are sometimes used interchangeably, but in some domains they have specific meanings (e.g. mechanical part, chemical element, part of a whole, part played by an actor or role).

The concept of “behavior or meaning of the whole not exhibited by the individual constituents” is often referred to as “emergence”, and is the defining characteristic of “systems” that distinguishes them from “non-systems”. However, we avoid using the term in this definition because of the risk of confusion with the other notion of “emergence”, which denotes surprise where such properties “emerge” that could not be foreseen or anticipated.

The goal of systems engineering is, then, to select, adjust, and arrange the parts or elements so as to achieve the desired whole-system properties when the system of interest is used as intended.

PHYSICAL AND CONCEPTUAL SYSTEMS

Systems can be either physical or conceptual, or a combination of both. Systems in the physical universe are composed of matter and energy, may embody information encoded in matter-energy carriers, and exhibit observable behavior. Conceptual systems are abstract systems of pure information, do not directly exhibit behavior, but exhibit “meaning”. In both cases, a system’s properties result, or emerge from:

- the parts or elements and their individual properties; AND
- the relationships and interactions between and among the constituents, the system and its environment; where:
- a “property” is an attribute, quality, or characteristic of something;
- “between” refers to binary interactions or relationships (binary means between two constituents), whereas “among” refers to relationships and interactions involving more than two constituents (in graph theory, such a relationship involving N parts or elements is referred to as “N-ary”);
- It is often argued that in physical systems we only need to consider interactions, but relationships are also important (e.g.. is part of, is assembled to, is vulnerable to, is owned by, costs, weighs....); interactions can be considered as a special type of relationship, but because of their importance in systems engineering, they are mentioned explicitly.

We can consider the structural ontology of physical and conceptual systems to be the same, at the fundamental level of parts and relationships – this is what allows us to model physical systems using conceptual systems; but the process ontology is quite different. A physical system can perform and manage processes internal to the system; whereas any change to, or use of, a conceptual system involves processes performed by external physical systems interacting with the conceptual system.

Thus:

PHYSICAL SYSTEMS

*A **physical system** is an arrangement of parts or elements that together exhibit behavior that the individual constituents do not. (This definition includes biological systems and living systems.)*

Physical systems are composed of matter and energy. Information is embedded in physical systems, and is stored and transported, in matter/energy carriers. The behavior of physical systems manifests itself as flows and exchanges of matter, energy and information, and interaction through force fields. The emergent property by which physical systems can be identified is that they perform processes to transform matter, energy and information in ways that their individual parts cannot. (NB “physical systems” includes biological and living systems, because they exist in the physical universe.)

Systems exhibit variable degrees of coupling and cohesion. A physical system may be a single complex object, such as an organism; or an “object aggregate”, a collection of objects that are inter-related in a way that makes them distinct from the rest of the universe. To be considered a system, the collection must exhibit observable properties not exhibited by the parts, separately or in other combinations: typically, transformation processes that cause observable effects, and binding processes that maintain observable cohesion.

Our knowledge of physical systems is ultimately limited by what can be observed, and is further limited by what observations we have chosen to make. Rosen (2012) explains this very clearly in terms of “the modelling relation” between models and observables. Our (inevitably partial) understanding of physical systems is expressed as models and narratives. (Allen & Starr, 2017)

“Observability” of a real system does not mean it is being, or has been, observed. It simply requires information about the system’s state and effects to be accessible, in principle, to a notional sensor or “meter”. What is observed depends a) on what an “observer” can, and chooses to, measure; b) on the frame of reference used for the observation; and c) (as Allen and Starr (2017) emphasize) on the scale of the measurement. Not all phenomena of interest can be observed directly; in practice, many are observed indirectly, essentially by inference due to cause-effect chaining.

CONCEPTUAL SYSTEMS

Conceptual systems are composed of information or knowledge. Information in a conceptual system can be stored or transported in a physical system by being encoded into the matter or energy states of the physical system. Thus:

*A **conceptual system** is an arrangement of parts or elements that together exhibit meaning that the individual constituents do not.*

A conceptual system is a “knowledge structure” and is composed of information and knowledge elements. The elements of a conceptual system are related to each other but do not interact with each other. The conceptual system interacts with physical systems which create, modify and interpret it. Its emergent property is meaning, as intended by its creator or editor. This depends on the semantics (meaning of the elements) and syntax (meaning of the relationships between the elements). The perceived meaning will match the intended meaning only if the semantics and syntax are shared between creator, editor and interpreter. A conceptual system can help us to interpret the state (past, present, or expected future) of the universe.

A conceptual system only exists as long as it is hosted in a matter/energy carrier, whether that is, for example, a computer memory, a book manuscript, tablets of stone, an idea in a biological consciousness, or information stored in DNA. Once the last record, consciousness or preserved pattern of the concept has disappeared, the concept has disappeared as well. (When the last copy of a book is burnt, the last file deleted, and the last person who read it has died or succumbed to dementia, that "conceptual system" has ceased to exist.)

Thus, conceptual systems are generated, evolve and decay not unlike physical systems. A practical case in point is computer software, an important kind of conceptual system, where the evolution of the code tends to be accompanied by an increase in entropy until the code becomes unmaintainable. The term "entropy" is often used in this context. The thermodynamic analogy holds well in terms of the increasing effort required to maintain software and keep it working as it becomes more disorganized.

The appearance or behavior of physical systems often embodies and conveys meaning. For example, poisonous animals may have distinctive markings as "warnings" to predators, and engineered products convey meaning with labels, the relationships between parts, or provide obvious affordances for interaction.

PHYSICAL AND CONCEPTUAL COMPONENTS OF ENGINEERED SYSTEMS

Engineered systems include products, services and enterprises. Services and enterprises usually depend on technological products but are essentially forms of socio-technical systems. "Engineered systems" may include hardware, software, firmware, processes, people, organizations, governance structures, information, knowledge, techniques, facilities, services, other support elements, and (usually modified) natural elements.

An important task in the "systems engineering" of engineered systems is therefore to establish or confirm the operational concept: how the system will be used to create value, while avoiding unintended negative consequences.

Thus, Systems Engineering involves both conceptual and physical systems; and engineered systems almost invariably include both physical and conceptual elements. In such cases, an engineered system can be thought of as a physical system and a conceptual system combined.

Even in the case of a pure "physical system", we make our systems usable, for example, by overlaying concepts that are embedded in the design as symbols, colors, shapes and other signs that convey meaning to the user on how to use the system, how to turn it on and off, which parts of the system are safe to touch, when is there some condition to be aware of, and so on.

Systems engineering often produces conceptual systems - models of the current "problem situation", the perceived problem or opportunity, and the envisaged future solution and the effect it will have on the problem situation.

Once the conceptual model of the proposed solution is demonstrated to have sufficient likelihood of solving or ameliorating the problem situation, that conceptual model becomes the blueprint for the physical system. The conceptual model of the proposed solution can be used as a reference point for the "as intended" system. The physical "as built" system can be compared to the conceptual model, and each may inform the other. The relative timing of the model activity and the build activity will depend on the balance of risk and reward for each project.

Once the physical system is deployed, we examine the effects produced by the system in the real world, and if necessary, update the conceptual models to reflect reality. These updated conceptual models are then used as the basis for changes to the system to meet changing needs and circumstances.

In the context of Systems Engineering, another very important form of conceptual system is the "Process Instruction". This includes computer software, and also policy and process documents that tell people how to make, use, support and retire the system of interest. A process instruction is a conceptual system; whereas a process is a transformation of matter, energy or information, done to or by a physical system.

THE CONSTRUCTIVIST PERSPECTIVE – SYSTEMS AS CONCEPTUAL MODELS OF REALITY

In the constructivist worldview, a system is not something presented to the observer, it is something to be recognized by an observer. In such cases, the word "system" does not refer to existing things in the real world but rather to a way of organizing our thoughts about what is real and make sense. This constructivist view of reality states that systems do not exist in the real world independently of the human mind. In this view, a system cannot be understood by analysis of the parts because of their complex interactions and because purpose or meaning can only be perceived in the whole. A system (from this perspective) is in itself always an abstraction chosen with the emphasis on either structural or functional aspects. A system is then anything unitary enough to deserve a name. A system is thus represented by a set of variables sufficiently isolated to stay constant long enough for us to discuss it as a coherent whole. This notion of a system is one way we, as humans, can organize our thoughts about what we see, or conceptualize, about how relationships and interactions between parts or elements result in outcomes.

OPEN AND CLOSED SYSTEMS

A system can be either closed or open:

A **closed system** *is a system that is completely isolated from its environment.*

This is the definition commonly used in the system literature, which we have chosen to follow. This is different from the thermodynamics definition, which differentiates between systems that are "closed" (no material flow) and "isolated" (no material or energy flow).

The physical universe, as we currently understand it, appears to be a closed system.

An **open system** *is a system that has flows of information, energy, and/or matter between the system and its environment, and which adapts to the exchange.*

This a fundamental systems science definition. It differs from the meaning of "open system" in IT and related fields, where the term is used in the sense of "open system architecture" that allows for a vendor-independent, non-proprietary, computer system or device design based on official and/or popular standards.

All physical systems of interest to systems engineering are open systems. However, there can be special cases in systems engineering where it is convenient to treat a system as if it is closed, if there are no significant external relationships or interactions to contend with.

Entropy increases in a closed system. In open systems, the entropy is kept low, or decreases, essentially at the expense of entropy increasing somewhere else, so the entropy of the universe continues to increase. Thus, systems tend to maintain their organization at the expense of increased disorder elsewhere, which is a common cause of unintended consequences.

It follows that a more fundamental definition of "system" could be "a persistent region of low entropy (= high organization) in physical or conceptual space-time". Then, it would follow that "systemness is the phenomenon that allows regions of organization to persist in a dissipative universe".

NATURAL, ARTIFICIAL, AND HYBRID SYSTEMS

We now introduce our preferred terminology to distinguish between naturally occurring and human-made systems, while noting that many systems are a hybrid of the two, so this is not a binary classification.

A **natural system** *is a system that occurs in nature without intervention by human agents.*

Natural systems exhibit properties such as viability, resilience, and self-organization that offer exemplars for engineered systems. Biomimicry refers to the practice of using natural systems as patterns for artificial ones.

An **artificial system** *is a system constructed by human agents, or otherwise caused by them to come into being.*

Human agents can be humans, or they can be processes, methods or tools created by humans that effect change indirectly to create the artificial system.

A **hybrid system** *is a system with both natural and artificial elements, or a natural system influenced (e.g.. by selective breeding) or modified (e.g.. by genetic engineering) by intentional agents.*

An **engineered system** means a system - artificial or hybrid, **conceptual and/or physical** - that was properly systems-engineered in the sense of the definition. Otherwise a human-made system is artificial or hybrid, but not engineered. Of course, there can be the case of a badly engineered system – such as a system where the operational environment is not well anticipated and the "applicable constraints" poorly selected.

SOCIAL AND SOCIO-TECHNICAL SYSTEMS

Some authorities maintain that there are three kinds of system: natural, social and "artificial".

In this viewpoint, a social system is any system made up primarily of intentional agents, which is not driven by natural forces but rather the force of willpower and cunning and various other intentional qualities; while an artificial system is one composed of deliberately created artefacts.

The term "human activity systems" is often used for social systems where the intentional agents are humans. Groups of agents working to a common purpose are not unique to humans; many animals live in social systems, and there is a spectrum of social systems, ranging from those composed of humans where the social system is deliberately constructed and maintained and can adapt rapidly, to simpler ones such as ant colonies where the “intentional behavior” appears to be hard-wired in genetic material.

Systems Engineering takes place within a social system, and typically produces part or all of a socio-technical system, a system with closely coupled social and technical parts.

There are many definitions in the literature for these and related system types; we do not attempt to offer firm definitions for these categories.

SPECIAL CASES – SUBTYPES AND EXEMPLARS RELEVANT TO SYSTEMS ENGINEERING

BIOLOGICAL AND LIVING SYSTEMS

Biological and Living systems (Miller, 1978) are examples of a large and important class of dynamic open systems, which exchange energy and waste with their environment to maintain themselves, at the expense of increasing entropy in their environment.

Living systems exploit matter and energy as well as information and knowledge elements. Their behavior manifests itself through flows of material, energy, and information; but also through collective knowledge that is transferred from generation to generation. Living systems have both conceptual and physical aspects, but they are unique in that their emergent behaviors are associated with learning and adaptation. Human systems are especially accomplished among living systems in their ability to express meaning in the form of complex language and use that to drive emergent behaviors of other physical, conceptual, and living systems to their goals.

VIABLE AND SELF-REPLICATING SYSTEMS

There is a significant literature - Beer’s (1972) Viable Systems Model, Hitchins (2007) - on “viable systems”, using the term in the sense of “capable of existence and development as an independent unit”, or “capable of surviving or living successfully, especially under particular environmental conditions”. Successful biological and organizational systems are viable in this sense. Viability in this sense is also a desirable attribute of many engineered systems. Hence, we offer a definition:

A **viable system** *is an open system that, within certain environmental limits, can: sustain itself by exchanging matter, energy and information with its environment; detect and survive external threats; maintain and repair its internal organization in the face of disruption; and adapt to a changing environment (e.g.. by evolving its capabilities); while maintaining its internal equilibrium (homeostasis).*

Living systems, as well as being “viable”, are also self-replicating and capable of adaptation and evolution:

A **self-replicating system** *is an open system that, within certain life cycle limits, can: reproduce itself by exchanging matter, energy and information either with its environment or with a second system of a compatible type; and pass on its attributes to the reproduced child system.*

COMPLEX SYSTEMS

Of numerous ways of defining complex systems, this one seems useful and relevant to SE:

A **complex system** *is a system in which there are non-trivial relationships between cause and effect: each effect may be due to multiple causes; each cause may contribute to multiple effects; causes and effects may be related as feedback loops, both positive and negative; and cause-effect chains are cyclic and highly entangled rather than linear and separable.*

The non-trivial nature of the relationships in a complex system make the whole system non- deterministic, ambiguous or chaotic (in the mathematical sense that a very small change in initial conditions may produce a very large change in outcome), even if the individual relationships within the system are well understood.

Complexity as defined above is a property of the system of interest. Complexity is also created in the wider system comprising the system of interest and its stakeholders when the system is not fully understood, and when different stakeholders have different partial understandings of the system and of other stakeholders' concerns. A major goal of Systems Engineering is to reduce this "perceived complexity" by establishing shared and valid models of the system, in order to improve stakeholders' knowledge and understanding of the system and its context.

An example of cyclic cause and effect is the biological process of mutualistic symbiosis, in which each of a pair of systems uses the other's waste as raw material for its own processes. The systems import energy from the environment to sustain the symbiotic processes, so the second law of thermodynamics is not violated. The "Circular Economy" takes this concept and applies it to industrial value chains, to turn them into value loops that are closed cycle apart from import of energy. Waste from one process is the feedstock for the next. If the energy comes from the sun, the value loop can be sustainable as long as energy is available from the sun.

The INCOSE Complexity Primer (https://www.incose.org/docs/default-source/ProductsPublications/a-complexity-primer-for-systems-engineers.pdf) provides a concise introduction to complex systems.

The difference between Complicated and Complex is discussed in, for example, Snowden and Boone (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, may be dynamically reconfigurable, and continue to co-evolve with their environment throughout their life cycle.

ANTICIPATORY SYSTEMS

Finally, systems covered by Rosen's (1985, 2012) concept of "anticipatory systems" are ubiquitous in the natural world, and increasingly relevant to SE as we move towards intelligent and autonomous systems. An anticipatory system's present behavior depends upon anticipated ''future states'' or ''future inputs'' generated by an internal predictive model. The following definition is an interpretation, not Rosen's original.

An **anticipatory system** *is a physical system that has an internal model of itself and its environment and an internal decision-making function, enabling it to anticipate potential changes in the environment and make appropriate adaptations to be ready for the anticipated change.*

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APPENDIX: TYPICAL FEATURES OF SYSTEMS ENGINEERING

Systems Engineering considers and balances the business, technical, personal and societal needs of 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. The scope is the total or "whole system" solution, not just the engineered artifacts that may be key elements of the solution. Business needs deal with the factors that justify expenditure of time and resources on the activities that occur during the various stages of a system.

Systems Engineering (SE) focuses on ten key activities:

1. 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;
2. investigating the solution space, proposing alternative solution and operational concepts, weighing their value (viability, utility, benefit at cost) and selecting the optimal or most appropriate concept(s);
3. architecting a solution or set of solutions based on the selected concept(s) while considering potential concepts of employment and usage;
4. modelling (or otherwise evaluating) the solution at each relevant phase of the endeavor, considering both normal and exceptional scenarios, and an appropriate diversity of viewpoints, in order to:
    a. establish required capability and performance;
    b. increase confidence that the solution will work as expected and required, while avoiding or minimizing undesirable unintended consequences;
    c. ensure the solution is resilient and can evolve if required to adapt to anticipated or possible changes in the user needs and operational environments;
    d. provide ongoing prediction and assessment of system effectiveness and value;
5. defining and managing the interfaces, both within the system and between the system and the rest of the world (noting that increasingly, systems engineering is conducted in a brown-field rather than a green-field environment, so legacy systems may be a major or key part of the overall solution);
6. establishing appropriate process and life cycle models that consider complexity, uncertainty, change and variety, and implementing system management and governance processes for both development and through-life use and disposal;
7. proceeding with detailed design synthesis, integration, and solution verification and validation (*ensuring the solution is fit for the intended purpose*) while considering the complete problem (including aspects of dependability such as safety, security, reliability, availability, logistic support, and disaster recovery), all necessary enabling systems and services, and end-of-life processes (*e.g.. transition to a replacement system, recycling of the retired one, nuclear decommissioning and waste disposal…*);
8. providing the SE knowledge and information required by all stakeholder groups to ensure coherence of the whole endeavor – typically including a vision statement, 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 (*including common standards to ensure interoperability*), verification and validation criteria, analysis and interpretation of test and evaluation results, anticipated operational usage, and appropriate system configurations for different scenarios;
9. supporting transition to use, considering all aspects including people, processes, information and technology;
10. periodically re-evaluating status, risks and opportunities, stakeholder feedback, observed or anticipated unintended consequences, and anticipated system effectiveness and value, and recommending any

appropriate corrective, mitigation or recovery actions to ensure continuing system success. Such activities during the operational phase can include upgrade activities, obsolescence management, maintenance and repair activities, manufacturing changes, changing operational processes, user training, instituting metrics and incentives, assessing information quality and integrity, and making other changes to the system.

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 (if relevant), operation, evolution and eventual disposal.

SE is essentially collaborative in nature, working with and facilitating collaboration between all contributors to system success, recognizing the need to respect diverse points of view.

- In some projects and in some organizations, SE may include a strong governance, technical management and resource management component.
- In other projects and organizations, SE may have an almost entirely technical, advisory and "glue" role, if appropriate management and implementation structures already exist.
- SE may need to be applied at multiple levels of a complex project, program or enterprise.
- 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.

Fundamentally, SE is a learning journey; and the output of SE is information, and shared models. SE synthesizes and provides the information required to describe the solution system, and to enable its successful realization and use.

SE aims to provide effective solutions to complicated, complex and unprecedented problems, integrating the efforts of engineering and other disciplines and specializations. A high leverage task in the "systems-engineering" of engineered systems is to establish or confirm the operational concept: how the system will be used to create value, while avoiding negative consequences.

The difference between Complicated and Complex is discussed in, for example, Snowden and Boone (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, may be dynamically reconfigurable, and continue to co- evolve with their environment throughout their life cycle.

Most 20th century engineered systems were complicated; most 21st century engineered systems will be complex. In complex situations, we need to apply SE to the "ecosystem transformation" as well as to individual projects.

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