International Council on Systems Engineering

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Adaptability: A Characteristic of Complex Systems or a Confounding factor of Complexity?

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System Adaptability Definitions

- Adaptability is a broad concept whose meaning becomes more specific in its application domain
  - Basic dictionary definition of Adaptability: “to make fit (as for a new use) often by modification” (Merriam-Webster, Inc. n.d.)

- Early Definitions of System Adaptability
  - A normalized savings in switching from one product to another, emphasizing the costs (not just financial cost) as the main consideration - Gu, Hashemian, and Nee (2004)
    - Views Adaptability from the perspective of the cost (effort, structure, material) to make a change
  - The links from a design to other designs (i.e., outdegree or filtered outdegree) from that design - Ross, Rhodes, and Hastings (2007)
    - View Adaptability from the perspective of system relationships in the design space

- INCOSE System Adaptability Working Group defines System Adaptability as
  - System Adaptability is a system’s ability to satisfy mission and requirement changes, with or without modification

SEBoK System Adaptability page, https://sebokwiki.org/wiki/System_Adaptability, accessed 2 March 2025

System Adaptability

- System Adaptability has a number of perspectives and is specific to the system and the system context
  - It is an aspect of the system defined to an extent by the context in which the system is applied

- Complex systems incorporate Adaptability as a Characteristic describing the systems complexity

Complex Adaptive Systems (CAS)

- INCOSE Complex Systems Working Group defines Adaptability as characteristic of a complex system
  - Complex systems proactively and/or reactively change function, relationships, and behavior to balance changes in environment and application to achieve system goals.
- This is one of 14 characteristics of a Complex System

Characteristics of a Complex System

Characteristic	Definition
Diversity	The structural, behavior, and system state varieties that characterize a system and/or its environments.
Connectivity	The connection of the system between its functions and the environment. This connectivity is characterized by the number of nodes, diversity of node types, number of links, and diversity in link characteristics. Complex systems have multiple layers of connections within the system structure. Discontinuities (breaks in a pattern of connectivity at one or more layers) are often indications of complex system connectivity. Simple and some complicated systems may be characterized by simpler structures such as hierarchies.
Interactivity	The behavior stimulus and response between different parts of a system and the system with its environment. Complex systems have many diverse sources of stimulus and diverse types of responses. The correlation between stimulus and response can be both direct and indirect (perhaps separated by many layers of system connectivity). The types of stimuli and responses vary greatly. The levels of stimuli and responses can range from very subtle to very pronounced. The timeframe for system responses can vary hugely.
Adaptability	Complex systems proactively and/or reactively change function, relationships, and behavior to balance changes in environment and application to achieve system goals.
Multiscale	Behavior, Relationships, and Structure exist on many scales, are ambiguously coupled across multiple scales, and are not reducible to only one level.
Multi-perspective	Multiple perspectives, some of which are orthogonal, are required to comprehend the complex system.
Behavior	Complex system behavior cannot be described fully as a response system. Complex system behavior includes nonlinearities. Optimizing system behavior cannot often be done focusing on properties solely within the system.
Dynamics	Complex systems may have equilibrium states or may have no equilibrium state. Complex system dynamics have multiple scales orloops. Complex systems can stay within the dynamical system or generate new system states or state transitions due to internal system changes, external environment changes, or both. Correlation of changes in complex systems to events or conditions in the system dynamics may be ambiguous.

Watson, M. D., McKinney, D., Anway, R., Rosser, L. A., MacCarthy, J., Appreciative Methods Applied to the Assessment of Complex Systems, INCOSE IS2019, Orlando, FL.

Characteristics of a Complex System

Characteristic	Definition
Representation	Representations of complex systems can be difficult to properly construct with any depth. It is often impossible to predict future configurations, structures, or behaviors of a complex system, given finite resources. Causal & influence networks create a challenge in developing 'requisite' conceptual models within these time and information resource constraints.
Evolution	Changes over time in complex system states and structures (physical and behavioral) can result from various causes. Complex system states and structures are likely to change as a result of interactions within the complex system, with the environment, or in application. A complex system can have disequilibrium (i.e., non-steady) states and continue to function. Complex system states and structures can change in an unplanned manner and can be difficult to discern as they occur. The changes in the states and structure of a complex system are a natural function of (is often present in) the complex system dynamics. Changes can occur without centralized control, due to localized responses to external and/or internal influences.
System Emergence (general)	Features/behavior associated with the holistic system that are more than aggregations of component properties.
Unexpected Emergence (Complex)	Emergent properties of the holistic system unexpected (whether predictable or unpredictable) in the system functionality/response. Unpredictable given finite resources. Behavior not describable as a response system.
Disproportionate Effects	Details seen at the fine scales can influence largescale behavior. Small scale modifications can result in radical changes of behavior. Scale can be in terms of magnitude of effect or aggregate amount of change. Weak ties can have disproportionate effects.
Indeterminate boundaries	Complex system boundaries are intricately woven with their environment and other interacting systems. Their boundaries can be non-deterministic. The boundary cannot be distinguished based solely on processes inside the system.
Contextual Influences	All systems reside in natural and social environments and relate to these. In the relationship between the system and the natural and social environments there can be complexity. This complex interaction depends on the social application of the system. Social systems often strive to achieve multiple, sometimes incompatible, objectives with the application of the same system.

Watson, M. D., McKinney, D., Anway, R., Rosser, L. A., MacCarthy, J., Appreciative Methods Applied to the Assessment of Complex Systems, INCOSE IS2019, Orlando, FL.

Confounding Factors and Tiers of Complexity

- There are factors which compound system complexity
  - Social environment (i.e., operational environment, multiple user interaction)
  - Artificial Intelligence (i.e., automation, ability to adapt to conditions, expected or unexpected)
  - Environmental interactions
  - Even with a very simple system, there can be complexity in the environment, in the interactions between stakeholders, and/or other factors.
- System adaptability is seen with AI responses to conditions (Complex Adaptive Systems (CAS))
- There are three tiers currently identified in the complexity of a system

System Complexity Tier	Characterized by
Complicated	Assembly of static parts
Complex	Interactions of dynamic operations
Complex Adaptive	Application of Artificial Intelligence determining system responses

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System Adaptability: Characteristic or Confounding Factor? Both!

- System Adaptability is shown as a system characteristic
  - Manifests in switching costs, design linkages, system context change responsiveness
    - Application varies with system context

- System Adaptability is shown as a confounding factor in complexity
  - As the ability to adapt to a wider, more intricate set of changes increases, Adaptability increases the level of complexity in a system
    - Autonomous, artificial intelligence systems exhibit this ability to take
    - Simple logic responding to defined situations, into
    - Intricate, not fully predictive logic expounded into complex system behavior

Thank You!

Back Up

How Do We Model System Adaptability?

- System Modeling is governed by several Systems Engineering Principles
  - Principle 5: The real system is the perfect representation of the system.
  - Principle 6: A focus of systems engineering is a progressively deeper understanding of the interactions, sensitivities, and behaviors of the system, stakeholder needs, and its operational environment.
    - Sub-Principle 6(b): Requirements and models reflect the understanding of the system
    - Sub-Principle 6(e): Modeling of systems must account for system interactions and couplings
    - Sub-Principle 6(f): Systems engineering achieves an understanding of all the system functions and interactions in the operational environment
  - Principle 11: Systems engineering spans the entire system life-cycle
    - Sub-Principle 11(c): Systems engineering models the system
  - Principle 12: Complex systems are engineered by complex organizations
  - Principle 15: Systems engineering is based on a middle range set of theories.
    - Sub-Principle 15(a): Systems engineering has a systems theory basis
    - Sub-Principle 15(b): Systems engineering has a physical/logical basis specific to the system.
    - Sub-Principle 15(c): Systems engineering has a mathematical basis
    - Sub-Principle 15(d): Systems engineering has a sociological basis specific to the organization.

Watson, M. D., Farrington, P. A., Mesmer, B. L., ‘Engineering Elegant Systems, Theory of Systems Engineering’, NASA/TP–20205003644, August 2022.

Watson, M.D., Systems Engineering Principles, INCOSE Publication, August 2022

System Adaptability Modeling Summary

System Modeling Type	System Adaptability
System Relational Model a) SysML b) Requirements Management c) Discrete Event Simulation (DES)	Models System Adaptability Functions that are • Deterministic • Tractable in terms of system functions and effort to construct the model accurately (switching cost realized in model construction effort)
System Integrating Physics a) Mathematical Modeling b) Multidisciplinary Design Optimization (MDO)	System Adaptability functions are captured in integrated physics models • Where multiple modeling types (e.g., Thermodynamic, logical, optical, Biological) require a form of MDO that can model and effectively integrate the system functions from these various system types. • Complex behavior involving adaptability are captured in the physics or logic of the integrating physics functions.
System State Variables a) Goal Function Tree	System Adaptability defines system functions or system function attributes • System states can capture functional relationships that define complex system behavior but do not execute or show probability of options • System Adaptability should be tractable in functions and effort to construct the model accurately (switching cost realized in model construction effort)
b) State Analysis Model	Simulates system adaptation behavior extremely well • State relationships capture the complex system adaptability behavior • System states describing the System Adaptability must be represented accurately
System Value Model	System Adaptability is preference for the systems functional attributes • Switching costs can be modeled as a system value preference • This is a simpler model in terms of System Adaptability as the attributes drive the value • Value preferences of stakeholders is more complex for any system value model
Engineering Statistics	System Adaptability probabilities and statistical responses are modeled. • Limited based on ability to define all conditions leading to adaptable responses
System Dynamics Modeling	System Adaptability can be modeled to determine adaptability response paths from a number of difficult feedback loops • Can incorporate human interaction as part of the adaptability

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