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Development of an Instrument to Assess Capacity for Systems Thinking

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Abstract

With the rapid growth and integration in technology and information, the behavior and structure of complex systems presents escalating challenges. Complex systems are marked by high level of ambiguity, uncertainty, and emergence. These conditions impose challenges and difficulties for practitioners responsible to successfully manage and design complex systems. There is a fundamental need to have a cadre of individuals who are capable of dealing with increasingly complex systems and their problems. One response is Systems Thinking, which can provide a holistic thinking paradigm that opens new channels and opportunities to think differently about complex systems as a whole unit. This paradigm will enable individuals to avoid solving the wrong problems. The emphasis of this paper is to explore possible applications of a research-based instrument developed to capture the level of systems thinking for individuals who engage and design complex systems. The Systems Thinking Profiles produced by the instrument represent individual inclination to adapt a systemic perspective for engaging and solving complex system problems, and reflects a state that can be enhanced through training and/or education to improve capacity for systems thinking.

Keywords: systems thinking; complex systems; cyber physical systems; sociotechnical systems

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1. Introduction

The objective of this paper is to explore possible applications of the research-based, instrument developed by Jaradat (2015) to capture the level of systems thinking for individuals who engage and design sociotechnical complex systems.[1] In this view, individual capacity for systems thinking is characterized by the level of systems knowledge that one possesses, the individual's worldview, and the compatibility of his or her worldview, individual experiences, and interpretations of those experiences with the precepts of systems thinking.[2] The systems thinking profiles, an articulation of this metric, provide a baseline by which any shift in systems thinking capacity can be measured, through training and education that allows engineers improve their ability to manage the increasing complexity in the design and operations of complex systems, equipped with a worldview that embraces a more holistic perspective. The next sections will discuss the significance of systems thinking in the field of sociotechnical complex systems and the systems thinking paradigm. The following section will discuss the development of the instrument and its associated dimensions, which reflect the very nature of complex systems.

1.1. Systems thinking paradigm in complex systems

Cyber physical systems belong in the domain of complex systems, having certain properties such as interdependence among intensely networked systems. Failure and underperformance of complex systems can be attributed to sociotechnical issues exacerbated by inadequate knowledge of complex systems and lacking systems skills precluding effective design of modern complex systems. Systems thinking is becoming evermore necessary for solving complex problems, and is necessary for effective design, development, and governance of complex systems.[2] Research effort in complex systems is driven by the growing prevalence of complex systems in society, from smart cities and countries to the Internet of Things, and our need to govern these systems effectively. More than ever, a shift in worldview, toward systems thinking, is necessary to manage the increasing complexity that comes with the territory.

A comprehensive annotated bibliography reflecting the breadth and diversity of systems thinking by Lane and Jackson (1995) demonstrates the various perspectives of systems thinking that formed the field of systems thinking.[3] The field of systems thinking emerged from literature in general systems theory, complexity theory, cybernetics, systems dynamics, soft and critical systems, and learning systems, and continues to grow.[4] An interesting definition of systems thinking is provided by Senge (1990): "a conceptual framework, a body of knowledge and tools that has been developed over the past fifty years, to make the full patterns clearer, and to help us see how to change them effectively" (p. 7).[5]

Systems thinking embraces a different form of pattern recognition that embraces behavior generated by many interactions within the total system, enabling more insightful perceptions than traditional seeking of cause-effect relationships that dominates reductionist thinking.[6] This paradigm enables individuals to avoid solving the wrong problems precisely, as described by Mitroff (1998).[7] Boehm and Mobasser (2015) discuss potential problems occurring in cyber physical systems from a mismatch of system thinking, suggesting that software engineers with higher levels of systems thinking perform often better in multi-disciplinary project efforts than highly specialized knowledge in one aspect of a system's content, such as software technology.[8]

It is important to mention that there are no bad or good systems thinking profiles. The combination of different types of thinkers on a team provides necessary variations in worldview to effectively address complex systems. The individual's preference toward engaging in systems (or reductionist) thinking should be compatible with their purpose and designated objectives in the system. Neither thinking style is inferior. All systems thinking types including reductionist thinking are necessary in cyber physical system applications, for different objectives or in different areas. For instance, reductionist systems thinkers might be preferred when highly specialized knowledge of digital communications and control systems is required, whereas holistic or middle systems thinkers might be preferred in multidisciplinary collaborative and cooperative efforts, such as integrating critical infrastructure protection for multi-institutional cyber security mitigation and incident response.[9]

2. Development of a systems thinking instrument

Jaradat *et al.* (2014) and Jaradat (2015) conducted an exhaustive review of over one thousand articles in systems literature and extensive coding analysis in order to produce a set of attributes to assess systems thinking capacity at the individual level.[10,1] Seven attributes were derived from the grounded theory coding analysis that all complex systems, both natural and manmade, exhibit in varying degrees: interconnectivity, integration, evolutionary development, emergence, complexity, uncertainty, and ambiguity (see Table 1).

Table 1. Attributes of complex systems[1]

Attribute	Explanation
Complexity	High level of interrelationships among the individual systems and their components, technical/nontechnical components in the system. Complexity also entails contextual issues (circumstances, factors, conditions, or patterns that enable or constrain the system).
Integration	The process through which an entity (element, component, or subsystem) becomes part of a larger integral whole, producing emergent properties beyond those held by its individual entities, which surrender a level of autonomy to allow membership in a greater whole.
Interconnectivity	Includes the potential divergent worldviews, conflicting perspectives, interactions of the systems' hardware and software components, human social and culture identities, human interactions, and proliferation of information and people.
Ambiguity	The unpredictability of understanding system's behavior and structure comes from the lack of clarity concerning essential aspects of the system (purpose, boundaries, structure), leading to doubt in decisions, actions, and interpretations in complex systems.
Emergence	Unintended behaviors and patterns that cannot be anticipated and cannot be attributed to any of the constituent systems. The structural and behavior patterns only become apparent as a complex system operates, occurring because of the uncertainty, high level of interactions, ambiguity, and complexity in complex systems.
Uncertainty	Incomplete and fallible knowledge exacerbates the occurrence of behaviors and patterns that were not intended, particularly well understood, or anticipated. This level of uncertainty increases complexity and the occurrence of rare events, therefore rendering decisions tenuous, and limiting the applicability of more traditional approaches and methods of analysis.
Evolutionary Development	Multiple perspectives, stakeholders and shareholders, who have direct or indirect impact on the system, contribute to the complexity and divergence of such systems, leading to issues such as the evolution of needs (requirements) over time and the necessary reallocation of scarce resources based on those shifts.

The resulting analysis was obtained with a sufficient level of stability necessary for the development of Jaradat's (2015) Instrument to Assess Individual Capacity for Systems Thinking.[1] The systems thinking instrument is developed based on the attributes mentioned in Table 1 to be more appreciative of the distinct differences in the sociotechnical complex system problems as opposed to more traditional problem domains. The purpose of the systems thinking instrument is to determine an individual's inclination to engage in higher level, holistic thinking about complex systems and approaching problems emanating from these systems.

3. Measuring individuals' systems thinking capacity for complex systems

The instrument developed by Jaradat (2015) contains 39 binary questions and generates different systems thinking profiles that establish individuals' predisposition to adapt a systemic perspective (High-Holistic Systems Thinker, Holistic Systems Thinker, Middle Systems Thinker, and Reductionist Systems Thinker) for engaging and solving sociotechnical complex system problems.[1] This section discusses the composition of the systems thinking profiles and how the resulting can be interpreted.

3.1 Systems thinking dimensions (outcome of the systems thinking instrument)

As shown in Table 2, the instrument consists of seven scales to measure fourteen major preferences. These fourteen categories reflect an individual's systems thinking capacity in dealing with complex system problems. The instrument assesses the individual on seven dimensions or preference pairs.

Table 2. Preference Pairs[1,2]

Systems thinking preference	Reductionist thinking preference
Complexity (C): Except under uncertainty, work on multidimensional problems, prefer a working solution, and explore the surrounding environment.	**Simplicity (S)**: Avoid uncertainty, work on linear problems, prefer best solution, prefer small-scale problems.
Integration (G): Preserve global integration; tend more to dependent decision and global performance level.	**Autonomy (A):** Preserve local autonomy, tend more to independent decision and local performance level.
Interconnectivity (I): Inclined to global interactions, follow general plan, work within a team, and interested less in identifiable cause-effect solutions.	**Isolation (N)**: Inclined to local interaction, follow detailed plan, prefer work individually, enjoy working in small systems, and interested more in cause-effect solutions.
Holism (H): Focused on the whole, interested more in the big picture, interested in concepts and abstract meaning of ideas.	**Reductionism (R)**: Focus on particulars, prefer analyzing the parts for better performance.
Emergence (E): React to situations as they occur, focus on the whole, comfortable with uncertainty, believe work environment is difficult to control, enjoy subjective and non-technical problems.	**Stability (T)**: Prepare detailed plans beforehand, focus on the details, uncomfortable with uncertainty, believe work environment is under control, enjoy objective, and technical problems.
Flexibility (F): Accommodate to change, like flexible plan, open to new ideas, unmotivated by routine.	**Rigidity (D)**: Prefer not to change, like determined plan, motivated by routine.
Embracement of Requirements (Y): Prefer taking multiple perspectives into consideration, underspecify requirements, focus more on the external forces, like long-range plans, keep options open, and work best in changing environment.	**Resistance of Requirements (V)**: Prefer taking few perspectives into consideration, overspecify requirements, focus more on the internal forces, like short-range plans tend to settle things, and work best in stable environment.

3.2 Interpretation of profile

After scores have been generated using an algorithm-score, an individual's systems thinking profile is attained. As shown in Fig. 1, there are four different types of profiles that are generated based on response data on seven scales.

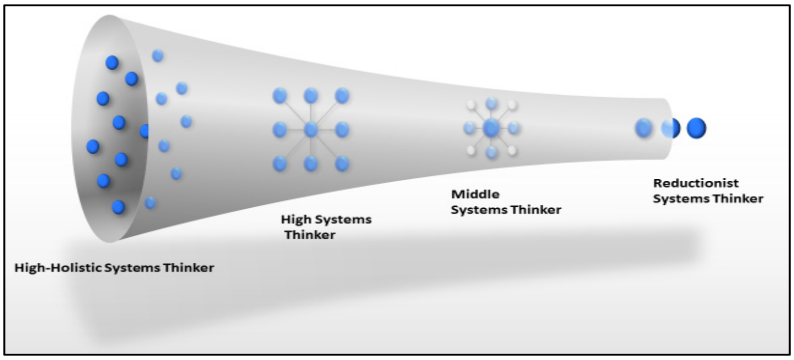

Fig. 1. Systems Thinking Spectrum

The detailed systems thinking profile consists of seven main letters that measure an individuals' systems thinking capacity and thus their inclinations to engage complex system problems. The first pair, *level of complexity (C-S)* describes an individual's comfort zone for engaging complex system problems. The second pair, *level of autonomy (G-A)*, describes an individual's inclination in dealing with integration of multiple systems or internal systems. For instance, (G)-type systems thinkers focus more on applying a global perspective and treat the system as an integrated unit. The third pair, *level of interaction (I-N)*, describes what type of scale an individual would choose to work with. The fourth pair, *level of change (Y-V)*, indicates an individual's propensity to accept change. The fifth pair, *level of uncertainty (E-T)*, describes an individual's preference in making decisions with incomplete knowledge. The sixth pair of preferences, *level of hierarchical view of the system (H-R)*, indicates the way an individual approaches problems within a larger complex system. An individual whose answers fall into the (H)-category is probably more interested in applying big picture concepts and ideas. Conversely, (R)-type systems thinkers prefer to focus on particulars and details. The last pair of preferences, *level of flexibility (F-D)*, describes an individual's preference to altering plans. In large complex system problems where the environment is changing rapidly, a flexible type system thinker is often preferable for coping with these environmental changes (i.e. implementation of new technologies).

4. Cyber security application case

The US Army has identified a need to develop assessment capabilities to support effective personnel selection and placement related to the emerging criticality of cyber work.[11,12] Current test methods are not viewed as particularly well suited for this assessment.[13,14] An enhanced test that is not dependent on technology knowledge and can be integrated with other assessment elements is sought.

The developed instrument can assist practitioners within cyber domain to better understand the complex landscape of their systems in three ways. First, decision-making is improved with respect to appropriate assignment of individuals based on their capacity for engaging complex systems. This is not to say that a "higher" score is superior; however, systems thinking profiles on this end of the spectrum indicate that certain inclinations characteristic of a systemic perspective are present that may be more suitable for engaging in, for example, work that is collaborative in nature and integrative of subsystems. Second, the scores facilitate team building that incorporates complementary perspectives in a measurable way. When establishing teams for projects and missions, knowledge of the variety of systemic perspectives individuals possess can be used to diversify the group. Third, the assessment is useful for determination whether or not sufficient capacity for systems thinking exists to engage in desired activities for a unit in focus. Stakeholders are better able to understand the system and its needs based on availability of system thinking capacity. Fig. 2 below shows examples of common systems thinking profiles generated by the instrument.

Fig. 2. Example of Common Systems Thinking Profiles

We believe that these different systems thinking profiles can make significant contributions across a spectrum of US Army mission support, advancing science (including methodological contributions) related to develop assessment capabilities to support effective personnel selection to the emerging complex system or system of systems problems. Contributions include:

1. *US Army Mission Support* – a top US Army priority is advancing capabilities for effective engagement in the Cyber theater. This research will aid early identification and prediction of success to support more effective investment and better personnel selection and management decisions.
2. *Advancing Science for Personal Assessment* – this effort will serve to make advances in measurement for a novel area (cyber) of vital importance to the future.
3. *Longer Range Research Program Implications* – The systems thinking instrument can work as a foundation in support of wider research that can expand the investigation and capability development to support the US Army desire to improve effectiveness of cyber personnel selection and placement.

5. Conclusions and implications

This paper provides a broad overview of possible applications of systems thinking instrument in dealing with sociotechnical systems. The instrument is applicable in many domains regardless of a system's domain of existence, including cyber physical systems, as it assesses an individual's capacity to approach and respond to complex problems in which systems thinking skills would be beneficial, independent of specific domain knowledge, skills, or abilities. The Systems Thinking Profiles generated by the instrument can be used to better assign individuals to work assignments on system problems that are compatible with their systems thinking skills and capacity.

The demand for individuals with systems thinking capacity, characterized by a measurable inclination to adapt a systemic perspective when engaging and solving complex system problems, continues to grow in many areas of complex system design, operation, coordination, governance, and evolution. The instrument responds to a need to measure systems thinking and assign individuals to responsibilities best suited for their inclinations, as well as to develop training programs for when a shift in perspective is necessary.

The necessary degree of systems thinking should be determined that is compatible for dealing with the governance activities related to the complex system of interest; for example, design, analysis, and strategic development. Based on the complexity of the system of interest, systems thinking available versus systems thinking required could be a useful metric for focusing training and education that teaches new ways to think about systems and frame systems problems.

It is difficult to say whether collaborative systems thinking (CST) for teams or organizations could be measured meaningfully by simply producing an aggregate score using the instrument, as it has been suggested that CST is an emergent behavior of teams that utilizes a variety of thinking styles in consideration of systems attributes, interrelationships, context, and dynamics towards executing systems design.[15] The field could benefit from future research in this area.

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