System of Systems Engineering

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Abstract: The purpose of this article is to develop the concept, foundations, research directions, and practice implications for System of Systems Engineering (SoSE). First, we introduce the nature of the complex systems problems faced by SoSE. Second, current perspectives of system of systems are explored. These perspectives are synthesized to a set of common themes in the literature and shortcomings in the current state of SoSE are identified. Third, we provide our perspective of SoSE, with implications for design, deployment, operation, and transformation of complex systems of systems. Fourth, we propose the structure for a research agenda to advance the knowledge and practice of SoSE. We close by developing implications of SoSE for systems engineering practitioners.

Engineers of future complex systems face an emerging challenge of how to address problems associated with integration of multiple complex systems. Numerous systems exist that alone can be considered complex systems. Examples of complex systems might include a metropolitan light rail system or an aircraft carrier. However, both of these complex systems could become a subsystem within a larger system of systems. Consider the light rail system that must be integrated into a metropolitan transportation system of systems, including private vehicles, air transport, buses, and other transportation systems. In the case of the aircraft carrier, we envision integration of the carrier with an array of other weapons platforms, communication systems, command structures, and computer systems—brought together as an integrated battle system of systems. Complex systems that have been conceived, developed, and deployed as stand-alone systems to address a singular problem can no longer be viewed as operating in isolation. Systems are being asked to perform missions as subsystems in integrated complex metasystems—systems that integrate multiple complex systems. Future demands will require metasystems to be engineered to function effectively as an integrated complex system of systems.

There seems to be little argument concerning present shortcomings in our abilities to deal with difficulties generated by increasingly complex and interrelated systems of systems. Beer's (1979) observation about complex systems still holds –we are dealing with a jigsaw puzzle that is about five miles across and we are standing on the ground trying to see how to fit it together. Since Beer's observation unprecedented explosive growth has taken place in technology, artifacts produced by technology, and information access has risen exponentially. However, we seem no more able to address Beer's puzzle than when he identified it over 20 years ago. In fact, it appears that we now have a problem centered on integrating multiple five-mile diameter jigsaw puzzles that change as we try to fit the pieces together.

System of Systems Engineering (SoSE) is emerging as an attempt to address integrating complex metasystems. However, SoSE is in the embryonic stages of development and lacks consistent focus. The concept of SoSE has received attention in literature (Carlock and Fenton, 2001; Kotov, 1997; Lukasik, 1998; Manthorpe, 1996; Pei, 2000; Sage and Cuppan, 2001). Unfortunately, SoSE is primarily being addressed as an information technology issue having a broad objective of getting everything to work together. Terms such as interoperability, platform integration, systems architecture, and information intensive have emerged to capture the information dimension of this new class of complex systems.

The state of the system of systems literature is a fragmented collection of seemingly disparate perspectives on the associated phenomena. This is to be expected in the early stages of concept development. Care must be taken in the beginning stages of theory (discipline) development not to narrow quickly, possibly

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