ASEE's 123rd Annual • Conference & Exposition • New Orleans, LA • June 26-29, 2016

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Paper ID #14643

Towards a Systems Theory-based Curriculum for Complex Systems Governance

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Dr. Bradley has had an extensive career in ship operations, maintenance, repair and organizational design. Repeatedly called upon to start new activities for the United States Navy, he successfully met a succession of unique challenges. Respected for his technical skill, leadership, innovative solutions and focus on personnel and organization development, he led efforts to improve quality performance, and developed educational programs to improve individual and organizational performance. Dr. Bradley's research has led to the creation of a wholly new approach to the creation, development, assessment and transformation of competency models, a vital management element in any large technical organization seeking long term viability. Dr. Bradley founded Leading Change, LLC as a vehicle to continue research and consulting to industry and government. Immediately in demand, he is assisting several organizations in what can only be characterized as global, long term, complex problems

Towards a systems theory-based curriculum for Complex Systems Governance

The purpose of this paper is to explore challenges associated with the development of a curriculum for an emerging field of *Complex System Governance* (CSG) that could be used for instruction and teaching leaders, managers, and students interested in increasing their knowledge, skills, and abilities about CSG. CSG has been suggested as a means to (1) explore deep system issues impacting performance, (2) introduce practitioners to new thinking, technologies, tools, and methods to address these issues, and (3) institutionalize capabilities to continuously advance governance. As with all new approaches, a curriculum in an emerging field is an essential element for the field's development. The paper discusses ongoing efforts and approaches to develop CSG body of knowledge along with initial insights into a curriculum for learning and doing effective governance.

Background

The 21st century has been described as a period of gradual deterioration of resources due to human mismanagement.[1] Certainly, this operational landscape is consistent with the notions of 'messes' where problems are interrelated, not well formulated, understood, or easily resolved [2] and 'wicked problems' where problems are intractable with the levels of thinking, decision, action, and interpretation.[3] This landscape has also been described in terms of ambiguity, complexity, emergence, and interdependence. Ambiguity in a sense that there is increasing lack of clarity and situational understanding. Complex in terms of large numbers of richly and dynamically interacting systems and subsystems with behavior difficult to predict. Emergence in terms of inability to deduce behavior, structure, or performance from constituent systems and interdependence in terms of the mutual influence among different complex systems through which the state of a given system influences and influenced by the state of other interconnected systems. [4] [5] [6]

Certainly these conditions are not new to systems and practitioners who must deal with systems in current operational environments. However, these conditions appear to be accelerating, acting to exacerbate the inherent difficulties in dealing with complex systems. Moreover, the problem space associated with this landscape evokes the need for systemic thinking with respect to its emphasis on understanding the structure and behavior of complex systems as wholes rather than isolated parts.[7] [8] [9] Consequently, researchers at the National Centers for System of Systems Engineering (NCSOSE) are investigating how to deal with systems in this landscape --- addressing the underlying conceptual foundations that can be used as a basis for methodologies, methods, tools, and techniques that could be used to understand and effectively deal with complex system behaviors.[10] A key piece of this emerging research is the development of an approach, *Complex System Governance* (CSG) to improve system performance through purposeful design, execution, and evolution of essential system functions. From a learning perspective, there is a need to increase knowledge, skills, and abilities of those that might be interested in CSG including government leaders, enterprise managers, and students. This paper explores challenges in developing a curriculum for CSG that could be used for instruction and teaching purposes. Insights from current efforts at Old Dominion University are provided.

Literature review

It is generally accepted that there is a need for robust methodologies capable of holistically and systemically analyzing behaviors of complex systems in current landscape.[11] [12] [13] It fact, there is no shortage of methodologies that promote systemic thinking and holistic identification of factors affecting complex systems.[14] Table 1 represents a selection of methodologies for intervening in complex systems. A rigorous description and critiques of these methodologies is provided elsewhere.[15] [16] The context of a problematic situation and purpose of analysis are two main factors that determine selection and use of the different methodologies.[17] CSG might be added to this listing since it shares the underlying theoretical underpinnings of systems theory and management cybernetics.

Table 1. A classification of methodologies for intervening in complex systems

Classification	Systems-based Methodology	Description	Primary Proponents
Hard Systems Thinking	Systems Analysis	Provides six iterative phases to study complex systems problems, including System Goals, Ranking Criteria, Alternative Development, Alternative Ranking, Iteration, and Action	Atthill[18]; Digby[19]; Gibson et al.[20]
	Systems Engineering	Structured formulation, analysis and interpretation of the technical, human, and organizational aspects of complex systems to address needs or resolve problems subject to cost, schedule, and operational performance constraints.	INCOSE[21]; Blanchard and Fabrycky[22]
	Operational Research	An analytical approach to problem solving and management based on determination of the mathematical optimal, or most efficient, means of achieving an objective	Churchman, et al.[23]
Soft Systems Thinking	Systems Dynamics	Computer modeling and simulation approach to understand the relationships and underlying behavior of complex systems.	Forrester[24]; Sterman[25]
	Organizational Cybernetics	Diagnosis of structural system functions, relationships, and communications channels necessary for any system to maintain existence.	Beer[26] [27] [28]
	Strategic Assumption Surfacing and Testing	Focuses on the resolution of ill-structured problems by identifying multiple stakeholders, their assumptions, and engaging in dialectical debate over proposed strategies to develop a higher-level course of action	Mitroff and Emshoff[29]; Mason and Mitroff[30]
	Interactive Planning	Continuous organizational planning to design desirable futures and develop strategies to achieve that future through participation, management structures, planning, and process	Ackoff[31] [32] [33] [34]
	Soft Systems Methodology	A process of inquiry focused on formulation of ill-structured problems appreciative of multiple perspectives	Checkland[35] [36]; Wilson[37]
	Systems of Systems Engineering Methodology	An approach to design, analysis, operation, and transformation of metasystems, composed of multiple embedded semiautonomous subsystems	Adams and Keating[38] [39]; Keating et al.[40]

Classification	Systems-based Methodology	Description	Primary Proponents
	Critical Systems Heuristics	A process of critical reflection based on a set of boundary questions that examine the legitimacy of designs by contrasting what ‘is’ proposed versus what ‘ought’ to be	Ulrich[41, 42]
	Organizational Learning	Makes explicit individual and organizational models that enable organizations to make explicit and test tacit structures and patterns which generate system behavior	Argyris and Schön[43, 44]
	Sociotechnical Systems	Work system analysis and redesign based on joint optimization of the social and technical subsystems for performing work	Trist and Bamforth[45]; Cherns[46]
	Total systems Intervention	A system problem solving approach based on creative thinking, appropriate method selection, and implementation of method based change proposals to resolve complex issues	Flood and Jackson[47]; Flood[48]; Jackson[49]

Complex System Governance

Complex System Governance (CSG) takes a purposeful, 'holistic', and comprehensive approach to more effectively deal with complex systems and their inherent problems. CSG has been previously identified as an emerging field dedicated to guiding design, execution, and evolution of nine essential metasystem functions that are required to sustain and evolve system performance.[50] A metasystem can be defined as a higher logical order beyond a single system of interest.[51] Systems theory and management cybernetics form the foundations of CSG. Systems theory is taken as a "unified group of specific propositions [laws, principles, and theorems] which are brought together to aid in understanding systems, thereby invoking improved explanatory power and interpretation with major implications for systems practitioners".[52] This view of systems theory is consistent with von Bertalanffy's[53] concepts of general systems theory where there is need to "concentrate on structure on all levels of magnitude and complexity, and fit detail into its general framework…discern[ing] relationships and situations, not atomistic facts and events".[54] Management cybernetics is a field of science concerned with developing high performing effective organizations. This field emerged from Stafford Beer's research into the concepts of viability. It evolved into the viable system model (VSM), in which Beer envisioned the necessary and sufficient subsystems and their functions for organisational viability (continued existence) despite turbulent environmental conditions.[55]

In CSG, the systems theory and management cybernetics are combined to offer propositions governing the system in the areas of integration and coordination while focusing on communication and control necessary for an effective organization. Table 2 illustrates the contributions of systems theory and management cybernetics to the emerging field of CSG.

Table 2. Foundations of CSG

Field	Proposition	Brief description of the contribution to Complex System Governance
Systems theory	Integration	Continuous maintenance of system integrity. This requires a dynamic balance between autonomy of constituent entities and the integration of those entities to form a coherent whole. This balance produces the system identity (uniqueness) that exists beyond the identities of the individual constituents.
	Coordination	Providing for interactions (relationships) between constituent entities within the system, and between the system and external entities, such that unnecessary instabilities are avoided.
Management cybernetics	Communication	The flow, transduction, and processing of information within and external to the system, that provides for consistency in decisions, actions, interpretations, and knowledge creation made with respect to the system.
	Control	In essence, the primary function of control by the metasystem in CSG is to provide the minimal constraint necessary to ensure continued system performance and behavior, while maximizing autonomy of governed entities.

A reference model has been developed in relation to CSG. [56] Full descriptions of these functions, nine in total, and their role in effective governance can be found in Keating and Bradley.[57] All viable (continuing to exist) systems perform these functions. The degree of system effectiveness is determined by how well these functions are performed. Moreover, the viability functions are interrelated, with none of the functions operating independent of the other functions, and no function being considered as 'more important.' Therefore, "all of the CSG Reference model functions are necessary to ensure the continuing viability of the System in Focus. Poor performance of one metasystem function will propagate through the entire metasystem. The metasystem functions are performed through associated mechanisms (the particular implementing devices that execute the metasystem function and exist in relationship with other mechanisms within the metasystem). The set of mechanisms and their interrelationships provide the structure that permits performance of the metasystem functions".[58] Figure 1 depicts the interrelationship among the nine functions of the CSG Reference Model.

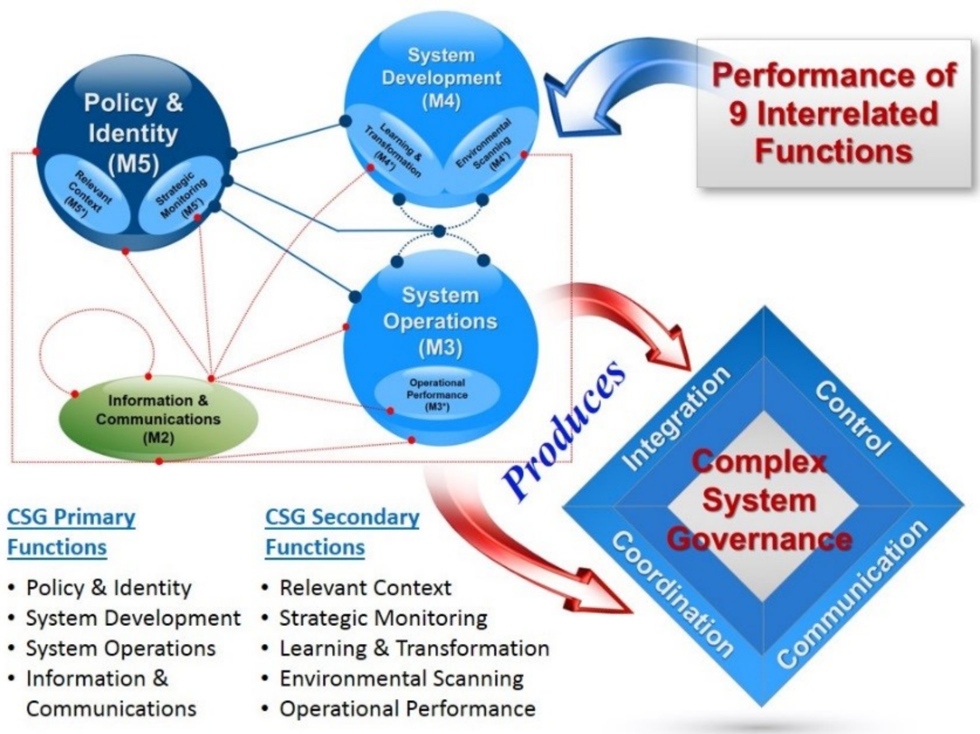

Figure 1. Foundations and interrelated functions of CSG Reference Model

Challenges for CSG

Realizing the potential of CSG an approach for intervening in systems operating under the previously articulated conditions involves many facets of research including applications and dissemination of knowledge. The utility of this emerging research could be demonstrated in failure and success stories outlining applications of the research. The research at NCSOSE has already developed the following in relation to the proposed approach:

- **Systems Theory Systemic Foundation:** Developed utility of different laws, principles, and theorems that describe structure and behaviors of complex systems.

- **Entity Competence for Systemic Thinking:** Provides the level of knowledge, skills, and abilities related to systemic thinking for organizations (systems) contemplating engagement in CSG development.
- **Reference Model Requirements Assessment:** Provides an examination of the function of CSG against the requirements specified for the CSG Reference Model.
- **Framing Methodology:** NCSOSE developed a methodology that could define the system of interest. The purpose is to enable making explicit relationships, transformation, and boundaries of systems, subsystems, and entities of focus the development effort.
- **System Leadership Assessment:** Outlines an approach that examines the degree to which the existing state of leadership is consistent with CSG for development expectations.
- **Individual Capacity for Systemic Thinking:** Establishes the level of systemic thinking that exist among stakeholders (i.e., owners, operators, designers, or performers) with respect to design, execution, and development of the metasystem.
- **Environmental Scanning:** Elaboration on the need to provides design for sensing of the external environment and identification of environmental patterns, activities, or events with system implications.
- **Pathologies for CSG**: A report of over 80 circumstances/conditions (pathologies) that act to limit system performance. The evaluation of these pathologies enables leaders and managers to understand that current state of their system and to develop countermeasures against the identified pathologies.
- **CSG methodology:** A three phase development (i.e., initialization, readiness level assessment, and governance development) methodology that rests on governance functions that must be performed by any system to maintain viability (existence).

Arguably, these developments represent a CSG body of knowledge available for leaders, managers, and students interesting in understanding and intervening complex systems from a CSG perspective. Current research efforts include insights into approaches that might be used to learn the CSG approach as well as knowledge dissemination.

Development of CSG through a Learning Community

Much of this CSG research was developed through a series of ongoing seminars, within the context of a learning community, which continues to offer insights into potential approaches for instruction and teaching CSG. Arguably, anyone interested in CSG might need to understand the domain in which CSG is supposed to offer utility. Moreover, a structured approach, such as a curriculum-based approach, could be developed to articulate the CSG field, its importance as well as the requisite foundational knowledge associated with CSG body of knowledge.

The current learning community is composed of masters and doctoral students, doctoral candidates and interested faculty. Our initial outlook of this emerging field includes the need to have (1) **semi-structured discussions** as a selected approach to discussing the various elements of CSG. This structure provides room for dialog and exchange of thoughts that could enable understanding the landscape and means that could be undertaken to address issues in systems of interest. These discussions are a recursive expression of the proposition of complementarity of systems theory, (2) ultimately, systems thinking serves as the foundation of CSG and as such

familiarity with literature in systems theory is necessary to engage in dialog. Since each member of the learning community has access to current body of knowledge, including development of methodologies, models, and tools, the learning process tends to be easy even for new members. Members are always challenged to find 'faults' in the current body of knowledge especially in the context of dealing with different complex systems (i.e., understanding and intervening), and (3) knowledge on CSG is never complete and as such there is always need for **continuous learning**. Continuous learning is an essential element of continuous understanding and learning about complex systems especially since complex systems change over time. Therefore, there is always a need to examine the utility of a method, tool, or technologies associated with CSG.

Presently, we do not have a formal curriculum for CSG. However, several components that might be included in a curriculum are proposed, based on current insights:

- **The use of workshops**: We have conducted several workshops whose aim is to introduce different audiences to key components of CSG. Members of the audience range from CEOs to graduate students. Topics have included the CSG Reference Model, how to initiate a CSG review at an organization and different research elements as discussed above.
- **Hold sessions on specific topics**: These sessions tend to focus on interest of stakeholders - members of the learning community. The discussions are often led by interested member who develops the theme based on conceptualization of CSG such as environmental scanning, system pathologies and system leadership.
- **Writing and dissemination of research**: Members of the learning community often find a measure of satisfaction and learning through theoretical research (i.e., discerning about CSG) and case applications (i.e., applying the research to different domains such as acquisitions, cyber-physical systems, and water utilities). The resulting research serves two purposes: First, refinement of the CSG field and second, community understanding of CSG. Table 3 contains a sampling of a number of the topics covered for a potential CSG curriculum based on those addressed in the various learning sessions.

Our assessment of this approach is that it works wonderfully to expose many concepts necessary for an emerging field – why? First, the structure of the sessions allows the entire community to engage in an interchange of ideas giving a broader examination of those ideas that originate with one or two participants. Second, the research workload is typically distributed over a larger number of participants rather than being concentrated in only a small number allowing more rapid development of topics of interest. Third, we find that having students whose interests are closely aligned to the core ideas of CSG, enables knowledgeable engagement with generally research backed assertions rather than purely opinion based discussions. However, we find that there is one major disadvantage of the current approach: There is a barrier for new student entry. It appears that a new member needs to absorb and understand the background theory and the developed material before becoming an effective contributor to different topics.

Table 3. A sampling of potential topics for CSG curriculum

	Sample topic	Brief topical description and approach used
Workshops	CSG Reference Model	• A series of workshops was used to develop and populate the CSG Reference Model.[59] • Additional workshops and material are planned for year 2016.
	Case studies	• Examination of a well-known complex systems through the lens of CSG to offer new insights previously unexplored. Funded efforts often include collection of firsthand data, analysis, and presentation of a final report. • Case studies serve to enhance leader, manager, or student understanding, but also serve to improve CSG body of knowledge.
Student/member Presentations	Environmental Scanning	• Student led discussion of 11 different fields' approach to environmental scanning. Student conducted research and distributed papers and presentation week before the session to allow fellow participants' preparation.
	Pathologies	• Student led discussion of organizational pathologies. Student conducted research and distributed papers and presentation week before to session to allow fellow participants preparation.
Writing Assignments	Journal Quality papers and conference proceedings	• Each student prepares a minimum of one, often more, papers that are turned into quality conference papers. • Over 10 conference papers have been presented in the US and Australia. • Over 15 journal papers have been published in respected academic journals. • Currently, the NCSOSE is involved in efforts to publish a textbook capturing CSG theory and actions.

Future Research

Proposed future research includes results of case applications in different problem domains (e.g., water utilities) based on the CSG perspectives. Development of formal curriculum that could be in instruction of business leaders, managers and students presents another venue of research. This research might include 'best-approaches' in different settings (e.g., a university, mentoring programs). However, these efforts should not diminish the utility of the present CSG body of knowledge especially for those who must deal with complex systems. The reference model alone offers an approach that could be used to evaluate complex system performance. Reference model knowledge is needed by practitioners operating their systems in the current environment. While a formal curriculum that might be used teach and evaluate leaners does not presently exist, components of such as approach are readily available including reading materials, tools, and technologies that can be used to understand and effectively deal with complex systems.

Acknowledgements

The authors gratefully acknowledge support from the National Centers for System of Systems Engineering at Old Dominion University. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Centers for System of Systems Engineering.

References

[1] Tainter, J. A. (1988). *The collapse of complex societies*. New York, NY: Cambridge University Press.

[2] Ackoff, R. L. (1974). Systems, messes, and interactive planning. In *Redesigning the future: Systems Approach to societal problems* (pp. 20–33). New York: NY: John Wiley & Sons Inc.

[3] Rittel, H. W. J., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, *4*(2), 155–169.

[4] Katina, P. F. (2015). *Systems theory-based construct for identifying metasystem pathologies for complex system governance* (Ph.D.). Old Dominion University, United States -- Virginia.

[5] Katina, P. F., Keating, C. B., & Jaradat, R. M. (2014). System requirements engineering in complex situations. *Requirements Engineering*, *19*(1), 45–62.

[6] Keating, C. B., Katina, P. F., & Bradley, J. M. (2014). Complex system governance: Concept, challenges, and emerging research. *International Journal of System of Systems Engineering*, *5*(3), 263–288.

[7] Laszlo, E. (1996). *The systems view of the world: A holistic vision for our time*. Cresskill, NJ: Hampton Press.

[8] Hammond, D. (2002). Exploring the genealogy of systems thinking. *Systems Research and Behavioral Science*, *19*(5), 429–439. http://doi.org/10.1002/sres.499

[9] von Bertalanffy, L. (1968). *General system theory: Foundations, developments, applications*. New York, NY: George Braziller.

[10] Keating, C. B., & Katina, P. F. (2015). Editorial: Foundational perspectives for the emerging complex system governance field. *International Journal of System of Systems Engineering*, *6*(1/2), 1–14.

[11] Conrad, T. P., & Gheorghe, A. V. (2011). Editorial: System of systems engineering in naval application. *International Journal of System of Systems Engineering*, *2*(2/3), 89–90.

[12] Jackson, M. C. (1991). *Systems methodology for the management sciences*. New York, NY: Plenum Press.

[13] Jackson, M. C. (2003). *Systems thinking: Creative holism for managers*. Chichester, UK: John Wiley & Sons Ltd.

[14] Katina, P. F. (2015). *Systems theory-based construct for identifying metasystem pathologies for complex system governance* (Ph.D.). Old Dominion University, United States -- Virginia.

[15] Jackson, M. C. (1991). *Systems methodology for the management sciences*. New York, NY: Plenum Press.

[16] Jackson, M. C. (2003). *Systems thinking: Creative holism for managers*. Chichester, UK: John Wiley & Sons Ltd.

[17] Crownover, M. W. B. (2005). *Complex system contextual framework (CSCF): A grounded-theory construction for the articulation of system context in addressing complex systems problems* (Dissertation). Old Dominion University, Norfolk, VA -- United States.

[18] Atthill, C. (1975). *Decisions: West oil distribution*. London, UK: P.B. Educational Services.

[19] Digby, J. (1989). *Operations research and systems analysis at RAND, 1948-1967* (No. RAND/N-2936-RC) (p. 4). Santa Monica, CA: RAND.

[20] Gibson, J. E., Scherer, W. T., & Gibson, W. F. (2007). *How to do systems analysis*. Hoboken, NJ: Wiley-Interscience.

[21] INCOSE. (2011). *Systems engineering handbook: A guide for system life cycle processes and activities*. (H. Cecilia, Ed.) (3.2 ed.). San Diego, CA: INCOSE.

[22] Blanchard, B. S., & Fabrycky, W. J. (2006). *Systems engineering and analysis* (4th ed.). Upper Saddle River, NJ: Pearson - Prentice Hall.

[23] Churchman, C. W., Ackoff, R. L., & Arnoff, E. (1957). *Introduction to operations research*. New York, NY: Wiley.

[24] Forrester, J. W. (1961). *Industrial dynamics*. Cambridge, MA: MIT press Cambridge, MA.

[25] Sterman, J. D. (2000). *Business dynamics: Systems thinking and modeling for a complex world*. New York, NY: McGraw-Hill.

[26] Beer, S. (1979). *The heart of the enterprise*. New York, NY: John Wiley & Sons.

[27] Beer, S. (1981). *Brain of the firm: The managerial cybernetics of organization*. Chichester, UK: Wiley.

[28] Beer, S. (1985). *Diagnosing the system for organizations*. Oxford, UK: Oxford University Press.

[29] Mitroff, I. I., & Emshoff, J. R. (1979). On strategic assumption-making: A dialectical approach to policy and planning. *The Academy of Management Review*, *4*(1), 1–12.

[30] Mason, R. O., & Mitroff, I. I. (1981). *Challenging strategic planning assumptions: Theory, cases, and techniques*. New York, NY: Wiley-Interscience.

[31] Ackoff, R. L. (1974). *Redesigning the future: A systems approach to societal problems*. New York, NY: John Wiley & Sons.

[32] Ackoff, R. L. (1981). *Creating the corporate future*. New York, NY: Wiley.

[33] Ackoff, R. L. (1981). The art and science of mess management. *Interfaces*, *11*(1), 20–26.

[34] Ackoff, R. L. (1999). *Re-creating the corporation*. New York, NY: Oxford University Press.

[35] Checkland, P. B. (1993). *Systems thinking, systems practice*. New York, NY: John Wiley & Sons.

[36] Checkland, P., & Scholes, J. (1999). *Soft systems methodology in action*. Chichester, UK: Wiley.

[37] Wilson, B. (1984). *Systems: Concepts, methodologies, and applications*. New York, NY: John Wiley & Sons, Inc.

[38] Adams, K. M., & Keating, C. B. (2009). *SoSE methodology rev 0.2* (No. NCSoSE Technical Report 009-2009). Norfolk, VA: National Centers for System of Systems Engineering.

[39] Adams, K. M., & Keating, C. B. (2011). Overview of the system of systems engineering methodology. *International Journal of System of Systems Engineering*, *2*(2/3), 112–119. http://doi.org/10.1504/IJSSE.2011.040549

[40] Keating, C. B., Sousa-Poza, A. A., & Mun, J. (2004). System of systems engineering methodology. EMSE: Old Dominion University.

[41] Ulrich, W. (1983). *Critical heuristics of social planning: A new approach to practical philosophy*. Bern/Stuttgart: Paul Haupt.

[42] Ulrich, W. (1987). Critical heuristics of social systems design. *European Journal of Operational Research*, *31*(3), 276–283.

[43] Argyris, C., & Schön, D. (1978). *Organizational learning: A theory of action perspective*. Reading, MA: Addison-Wesley.

[44] Argyris, C., & Schön, D. (1996). *Organizational learning II: Theory, method, and practice*. New York, NY: Addison-Wesley.

[45] Trist, E. L., & Bamforth, K. W. (1951). Some social and psychological consequences of the Longwall Method of coal-getting: An examination of the psychological situation and defenses of a work group in relation to the social structure and technological content of the work system. *Human Relations*, *4*(1), 3–38.

[46] Cherns, A. (1976). The principles of sociotechnical design. *Human Relations*, *29*(8), 783–792.

[47] Flood, R. L., & Jackson, M. C. (1991). *Creative problem solving: Total systems intervention*. New York, NY: Wiley.

[48] Flood, R. L. (1995). Total systems intervention (TSI): A reconstitution. *Journal of the Operational Research Society*, *46*(2), 174–191.

[49] Jackson, M. C. (1991). *Systems methodology for the management sciences*. New York, NY: Plenum Press.

[50] Keating, C. B., Katina, P. F., & Bradley, J. M. (2014). Complex system governance: Concept, challenges, and emerging research. *International Journal of System of Systems Engineering*, *5*(3), 263–288.

[51] Krippendorff, K. (1986). *A dictionary of cybernetics*. Norfolk, VA: The American Society for Cybernetics. Retrieved from http://repository.upenn.edu/asc_papers/224

[52] Adams, K. M., Hester, P. T., Bradley, J. M., Meyers, T. J., & Keating, C. B. (2014). Systems theory as the foundation for understanding systems. *Systems Engineering*, *17*(1), 112–123. http://doi.org/10.1002/sys.21255

[53] von Bertalanffy, L. (1950). An outline of general system theory. *The British Journal for the Philosophy of Science*, *1*(2), 134–165. http://doi.org/10.1093/bjps/I.2.134

[54] Laszlo, E. (1996). *The systems view of the world: A holistic vision for our time*. Cresskill, NJ: Hampton Press.

[55] Beer, S. (1979). *The heart of the enterprise*. New York, NY: John Wiley & Sons.

[56] Keating, C. B., & Bradley, J. M. (2015). Complex system governance reference model. *International Journal of System of Systems Engineering*, *6*(1-2), 33–52.

[57] Keating, C. B., & Bradley, J. M. (2015). Complex system governance reference model. *International Journal of System of Systems Engineering*, *6*(1-2), 33–52.

[58] Keating, C. B., & Bradley, J. M. (2015). Complex system governance reference model. *International Journal of System of Systems Engineering*, *6*(1-2), 33–52.

[59] Keating, C. B., & Bradley, J. M. (2015). Complex system governance reference model. *International Journal of System of Systems Engineering*, *6*(1-2), 33–52.