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Author
Dr. Walter W. Buchanan
Professor and Past Head and
J.R. Thompson Endowed Chair Professor
at Texas A&M University

ATMAE
701 Exposition Place
Suite 206
Raleigh, NC 27615

www. atmae.org

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Dealing with Complex Systems: Some Educational Issues

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Dr. Walter W. Buchanan is a Professor and Past Head and J.R. Thompson Endowed Chair Professor at Texas A&M University. He has served in professorial and administrative positions at Northeastern University, Oregon Institute of Technology, Middle Tennessee State University, University of Central Florida, and Indiana University-Purdue University Indianapolis, was an electronics engineer for the Naval Avionics Center, an engineering officer for the Navy, an aerospace engineer for the Boeing and Martin Companies, as well as an attorney for the Veteran's Administration. He is a Fellow and served on the Board of Directors of both the American Society for Engineering Education (ASEE) and the National Society of Professional Engineers (NSPE) and is a Fellow Member of the Institute of Electrical and Electronics Engineers (IEEE) and ABET. He is on the editorial board of the Journal of Engineering Technology, has authored or co-authored over 250 publications, and has been a principal investigator for NSF grants. Buchanan is a Past President of ASEE and has received the ASEE Distinguished Service Citation and Centennial Certificate, the ASEE James H. McGraw Award, and the ASEE Frederick J. Berger Award. He was selected as a Highly Accomplished Engineering Educator by ASEE Prism in 2005. Buchanan was a charter member of the Tau Alpha Pi Board of Directors and served as President in 2003. He holds a B.S.E and M.S.E. from Purdue University, and a B.A., J.D., and Ph.D. from Indiana University. He is a registered P.E. in six states and is a retired member of the Indiana State Bar.

Dealing with Complex Systems: Some Educational Issues

Abstract

The aim in this paper is to explore the major issues involved in handling complex systems in university education. The plan is to question of how problems are related to different methodologies. A discussion will include some guidelines for selecting the most appropriate methodology for a given problematic situation. This will be followed by the presentation of a comparative view of three methodologies and some suggestions and a proposed set of topics for university educators. The subject matter is viewed from a Systems Thinking perspective, concentrating on the application of three selected methodologies. First, different approaches to complexity concept and complexity management within the body of General Systems Theory and Systems Thinking are reviewed. This is followed by a critical discussion on problem-context relationship and selection of the appropriate methodology for handling complexity at hand, and a comparative view of three popular methodologies (Soft Cybernetics, System Dynamics and Science of Complexity). The paper is concluded by an elaboration of the selected methodologies in the context of university level education and some suggestions for educators.

Introduction

Complex systems and complexity management are quite popular and challenging research areas in the systems movement. The first formal studies on complexity were seen in the early stages of the development of General Systems Theory (GST) (Gorze-Mitka & Okreglicka, (2014). GST, pioneered by Bertalanfy, was developed as a "metatheory" or "the theory of theories" (Skyttner, 2001 & 2006). Both complexity and large-scale systems have been attracting considerable attention in GST, and in all its major trends. The trends that are well known in GST are Systems Approach, System Analysis, Operations Research (OR), Systems Engineering (including Cognitive Systems Engineering), System Dynamics, System Design, Teleology, Science of Complexity, Cybernetics and Bionics. All these trends view complexity from different perspectives. Some pioneering studies on complexity were conducted by important names in systems movement, such as Churchman, Ackoff, Weinberg, Forrester, Gingch and others. One of the earliest formal studies on complexity was conducted by Weiner in his work on *Cybernetics*. Here, the idea was to explain a system's behavior by revealing "the underlying principles of structure" of the system via cause-effect relationships and feedback loops. Later, *Organizational Cybernetics* was developed, based on the same principles, except that it is applied to organizational issues. The emphasis in *Science of Complexity* is on the conditions under which *evolutionary, self-organizing* and *self-complicating* behavior emerge in systems. Science of Complexity is a multi-disciplinary area and it is relatively young compared to other methodologies; it has emerged as a new paradigm in GST in the last decades. It includes biological organization, computer mathematics, physics, parallel network computing, non-linear system dynamics, chaos theory, neural networks and connectionism.

One of the interesting studies on complexity was reported by Arévalo & Espinosa (2015). The study views complexity from a systems theoretical perspective and provides a comparative view of some methodologies for handling the matter. The methodologies considered are Complexity Theory, Complex Adaptive Systems (CAS) and Organizational Cybernetics. All these three methodologies aim to study nonlinear complex systems, but with different approaches. Spencer, on the other hand, sees industrial complexity as a concept of emergent property in the business world (Spencer, 2014). He suggests that managers can handle complexity through leverages in known cause-effect relationships, as it is done in System Dynamics. He also suggests that complexity can be managed by building interfaces and deconstructing complexity. A multi-disciplinary view of decision making in complexity was given by Swami where complexity decision making is seen as a cognitive process, including theories and concepts from psychology, behavioral economics, operations research, and managerial practice (Swami, 2013). In another study it is claimed that strategic decision-making in complex environments requires meta-cognitive skills that involve skills for innovative and adaptable decision models beyond linear thinking (Gorze-Mitka

& Okreglicka, 2014). Complexity decision making was also studied by Schiuma, Carlucci, & Sole (2012). They developed a Systems Thinking-based framework where knowledge assets are translated into organizational values for decision making. A similar framework developed by Wiek is interesting in the sense that it is mainly based on soft OR methods and a multi-methodological approach (Wiek & Walter, 2009).

The plan of this paper is as follows. The question of how problems are related to methodologies will be discussed in the next section. The discussion will include some guidelines for selecting the most appropriate methodology for a given problematic situation. This will be followed by the presentation of a comparative view of the three methodologies mentioned earlier and some suggestions and a proposed set of topics for university educators.

Problem-Context and Methodology Selection Issues

Jackson, (2000 & 2003) and Kurtz and Snowden, (2003) studied problem-complexity relationship and methodology selection issues and forwarded significant clues to system analysts for this difficult task. Essentially, both of these works formulate the same phenomenon, but from different perspectives. Jackson classifies problem-context in terms of six ideal-type forms of 'system' and 'participant' dimensions as follows: *simple-unitary, simple-pluralist, simple-coercive, complex-unitary, complex-pluralist* and *complex-coercive*. He then relates the problem context to the following classes of system methodologies: *(1) Functionalist Systems Approach, (2) Interpretive Systems Approach, (3) Emancipatory Systems Approach, (4) Postmodern Systems Approach,* and *(5) Critical Systems Thinking*. For instance, classical or hard OR belongs to a simple-unitary category. This is also true, to a lesser extent, for Systems Analysis and (classical) Systems Engineering. These methodologies belong to "hard school" where it is assumed that people share the same values and beliefs, and that systems are simple enough to be mathematically modeled. For instance, Hard OR methodology fits to this description; it is successful in tackling a whole variety of operational issues, such as, inventory control, queuing, scheduling, routing problems, etc. However, it fails in complex situations. In complex-unitary situations, System Dynamics, Organizational Cybernetics and Complexity Theory are found to be useful. Soft system approaches, on the other hand, are suggested in complex-pluralistic situations since it is almost impossible to model human interactions adequately via hard approaches (e.g. in socio-economic systems). It should be noted that the use of *Critical Systems Thinking* is suggested in many complex situations where the system analyst can make use of a number of methodologies in conjunction. The interested reader should see Jackson (2000 & 2003) and Flood and Carson (1998) for details. A multi-methodological may prove to be more effective than the use of a single methodology where both hard and soft (Jackson, 2000) can be combined. The reader will find a number of applications of the multi-methodological approach, including some in sustainability - e.g. application reported by Espinoza & Walker (2013).

The framework developed by Kurtz and Snowden in 2003, called the Cynefin sense-making framework, classifies systems as *Known, Knowable, Complex* and *Chaos*. The Known systems are systems that have perceivable and predictable cause-and-effect relationships and can be handled via Sense-Categorize-Respond type methodologies (e.g. process re-engineering). In the Knowable category, cause and effect are separated over time and space, and Sense-Analyze-Respond type methodologies are suitable - e.g. System Dynamics. Complex systems, on the other hand, are viewed as systems with cause-and-effect relationships that are coherent in retrospect and do not repeat; the appropriate methodologies for this category are the Probe-Sense-Respond type (e.g. pattern management). In chaotic systems, cause-and-effect relationships are not perceivable and can be handled only by the Act-Sense-Respond approach (e.g. crisis management). Complex decision-making situations normally fall into the Knowable and Complex Systems categories. Hence, Sense-Analyze-Respond and Probe-Sense-Respond type methodologies are needed to resolve complex decision-making situations.

A Comparative View of Selected Methodologies

The methodologies considered here are relatively young compared to the classical system methodologies. The classical methodologies such as OR, System Analysis and Systems Engineering are mainly based on mathematical tools. The idea here is that any problem can be solved by setting objectives and then finding from a range of alternatives the one solution that will be optimal. As stated earlier, these approaches prove to be inadequate in complex situations since it is difficult to formulate objectives and the means of achieving them via mathematics. For instance, conflict in strategies, decisions, and the means of achieving them leads to a new set of issues to be managed. These difficulties eventually channeled many researchers towards developing "soft" system methodologies, starting in the early 1980s (Checkland & Scholes, 1990) and (Checkland, 1993).

All Soft Systems Thinking methodologies acknowledge that there can be different perceptions of reality, and these different perspectives lead to different solutions. This is a philosophical breakthrough with "hard" system methodologies where there is one reality (the one and only one) and there is one best solution. For instance, *Soft Systems Methodology (SSM)*, one of the well-known methodologies, embraces a paradigm of learning rather than viewing the world as systems whose performance can be optimized by following systematic procedures (Checkland & Scholes, 1990) and (Checkland, 1993). Accordingly, there is no best model or the best solution. This particular methodology is found to be successful by many researchers (Jackson, 2003). Similar thinking can be seen behind *Senge's Systems Thinking, Soft OR, Soft System Dynamics, Cognitive Mapping, SODA (Strategic Options Development and Analysis)* and *Soft Cybernetics* (Daellenbach, McNickle & Dye, 2005) *and* (Maani & Cavana, 2007).

Within the context of GST, one of the earliest formal works on complexity was performed by Weiner; he dealt with this issue in his famous work on Cybernetics (Skyttner, 2001 & 2006). He argued that technological systems and living organisms can be studied in parallel, transferring knowledge and models from one area to the other. However, due to the hard nature of this methodology, it proved to be insufficient to handle complexity, particularly in socioeconomic systems. As a result, Organizational Cybernetics or Managerial Cybernetics was developed. Here organizations are viewed from the following multiple perspectives: as organisms; as control systems; as brains; as machines; as cultures; as political systems; as theatres; as instruments of domination; as information systems; as social contracts, etc. Organizational Cybernetics is known to be a "structuralist" approach where the relationships between feedback processes operating at the deep structural level are examined first. These findings are then used to determine the system behavior at the surface level. Designers normally use a combination of multiple perspectives when dealing with organizational complexity.

Science of Complexity is a multidisciplinary area that includes biological organization, computer mathematics, physics, parallel network computing, non-linear system dynamics, chaos theory, neural networks and connectionism. It aims to describe the laws of complexity and try to understand the natural world, and with its emergent properties. In this regard it is important to understand how *evolutionary, self-organizing* and *self-complicating* behaviors emerge in systems. *Self-organizing* and *autonomous systems* are also important in complexity management, and they are also the major issues in Cybernetics. Accordingly, everything in the living world goes from less ordered to more ordered states, which is an irreversible process. The process of increasing differentiation, structural organization, complexity and integration never stops, and that *evolution* creates individuals who are relatively more independent of the environment with greater autonomy. In turn, the level of consciousness is raised, generating more complex superstructures or ecosystems. It is believed that industries and corporations respond to changing technological development and try to survive through self-organization, just as it is in biological systems. The principles observed in species are interpreted and used to design better social organizations. Such designs create *systems that govern themselves*, proving to be superior to the traditional systems based on centralized control.

System Dynamics (SD) is based on what is known as Systems Theory. Like in all hard tools, modeling is performed primarily via mathematical relationships in Systems Theory. The most widely used method is based on the representation of systems via differential-difference equations, and positive and negative feedback loops. However, this classical approach does not allow the system analyst to include nonlinear, verbal and logical processes in the models. In contemporary System Dynamics, on the other hand, it is possible to model and simulate the non-analytical and nonlinear aspects of complex systems reasonably easily, hence making the representation of "soft" issues possible. This enables systems scientist to deal with complex systems more effectively (Jackson, 2003).

Some Suggestions for Educators

The first subject to teach students is the prerequisite material; they need to have sufficient background in Systems Thinking. The selected material should include both hard and soft approaches where a critical evaluation of major system methodologies is given. The educators may want to look at Jackson, 2003 where a comparative view of major system methodologies is given– a very valuable source. The next topic to teach them is the approaches to methodology selection. This topic should also include Critical Systems Thinking which guides the systems analyst to select a combination of appropriate methodologies in highly complex situations. The educator should note that Jackson, 2003 is fairly theoretical, and requires a relatively strong background in Systems Thinking. The framework developed by Kurtz and Snowden in 2003, on the other hand, seems to be easier to follow; it requires a modest background in Systems Thinking. It is the author's belief that it is vitally important to comprehend the nature of problem complexity and determine the most suitable approach or methodology. For that, students need to have a comparative view of systems methodologies and the approaches to methodology selection. It should be noted that the boundaries between different system and methodology categories are by no means clear; they are fuzzy.

As far as the three system methodologies outlined in the paper, the following important points should be kept in mind. In Organizational Cybernetics, Beer's VSM (viable system model) stands out to be a successful methodology. It is based on a living organism and it has the ability to *reconfigure* itself if its environment changes. This probably is the key characteristic that makes VSM rather successful. Unfortunately, the relative difficulties involved in learning this particular methodology limit its application. Those educators who have some background in control systems may prefer this methodology.

Understanding and applying Science of Complexity requires some background in differential equations and linear/nonlinear system analysis. The reader is reminded that Science of Complexity was reformulated as *Complex Adaptive Systems (CAS)* later at the Santa Fe Institute (Snyder, 2013). It appears to be relatively easier to learn and apply CAS which has a wide area of applications. One typical application of CAS is seen in supply chains where managerial system is modeled via CAS together with its emergent properties. It is believed that these properties cannot be modeled exclusively by other approaches; hence they produce less effective management structures (Christopher, 2012).

System Dynamics has become quite popular in the last decade or so and found applications in many areas, including ecological studies, supply chains, new product development, design of information systems and project management (Maani & Cavana, 2007)). It is argued that System Dynamics can be applied effectively and successfully when it is possible to identify cause-effect relationships in a system, in a manner similar to quantitative modeling and simulation techniques. The popularity of System Dynamics has increased dramatically in the recent decades as a result of the development of intelligent software packages such as IThink/Stella. These packages are equipped with tools for modeling soft indicators such as human moral, burnout, commitment, loyalty, confidence and capacity for learning, etc. - in addition to the conventional performance indicators like KPI (key performance indicator) and CSF (critical success factors). Furthermore, system analyst does not need to know the details of difference/differential algebra or computer programming. Due to the flexibility offered in modeling and analyzing highly complex systems, System Dynamics is employed extensively in complex system studies in wide ranging areas of applications -e.g. sustainability studies. The author of this paper thinks that it may be relatively easier to learn, teach and apply System Dynamics.

However, System Dynamics has some weaknesses. Its theoretical basis is weak when compared to Systems Theory. It is not possible to conduct pre-simulation analyses and study the structural properties of a system, such as stability, controllability, observability, etc., via System Dynamics. These analyses allow system analysts to perform useful initial studies on major system characteristics. Furthermore, there is always the risk of simplifying a complex reality via positive and negative loops, as mentioned before. Although this risk is always there in complex system studies, regardless of the methodology used, the reader should see Jackson (2003) for specific remarks related to the application of System Dynamics. However, there are some warnings that it can also be used poorly if the system complexity is simplified while modeling (Jackson, 2003).

The central theme in all the three methodologies mentioned is *Evolution* and *Self-Organization*. Evolution is seen as a progressive continuous change in Organizational Cybernetics and CAS, while it is interpreted as sudden changes in Complexity Sciences. In Organizational Cybernetics, self-organization takes place when there is redundancy of potential command in distributed control within the system. Complexity Sciences, on the other hand, explain the emergence of self-organization as a co-evolutionary process characterized by the absence of a central controller. For CAS, theory of self-organization arises from the adaptive capacity of the system to changing environmental conditions (Arevalo & Espinosa, 2015). The reader should also note that GST provides a strong theoretical framework for complexity management since it covers the important system concepts, theories and methodologies.

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Proposed Topics for Course Design

The following proposal has been developed to guide the potential instructors so that they can design a course on complexity management. The material is divided into two parts. Part I contains the essential topics whereas Part II is devoted to the review of the three selected methodologies.

Part I: Introduction to Systems Thinking and System Methodologies

Topics suggested:
Historical Development of Systems Thinking
Basics of General Systems Theory and Cybernetics
A Comparative View of Hard and Soft System Paradigms
Problem Context and Methodology Selection
Multi-Methodological Approach and Critical Systems Thinking

The aim in Part I is to provide a historical perspective of holistic thinking, which is a highly motivating topic for students. The instructor is recommended to make use of Skyttner's works in 2001 and 2006. Skyttner provides a highly readable review of historical developments by examining Systems Thinking during the scholastic period and Renaissance, and in the eras of the Classical Science, Relativity, Quantum Theory and Systems Age. It may be a good idea to look at the way he presents the basic concepts of General Systems Theory (GST) and its applications in artificial intelligence, management information systems and informatics. The instructor will find valuable information in these chapters. There is also a chapter on self-organization in the 2006 edition of the book, which is important in studies of complexity.

For the remainder of topics in Part I, the instructor is recommended to look at Jackson in 2003 and Daellenbach, McNickle, and Dye of 2005. The former is a theoretically strong book, but readable at the same time. It provides a historical view of systems movement and classifies all the major system methodologies, both hard and soft, from a social sciences point of view. The weaknesses and strengths of the methodologies are also discussed in Jackson's books, providing some insight into the art of choosing the appropriate methodology or methodologies. The multi-methodological approach and a review of Critical System are also covered in the book. Students of industrial engineering and business administration should find the book of Daellenbach, McNickle, and Dye in 2005 quite appealing. The book approaches complexity and decision making from an OR/system simulation perspective. It introduces Systems Thinking, basic system concepts, problem structuring techniques, system modeling via graphical approaches and analytical techniques. Also included in the book are hard OR methodology, soft system methodologies, simulation and system dynamics, and decision making and risk analysis. The instructor is recommended to discuss some case studies presented in the book (or similar ones) in the class to bring these rather abstract ideas "down to earth."

Part II: Fundamentals of Organizational Cybernetics, Complexity Science and System Dynamics
Topics suggested:
Self-Organizing and Autonomous Systems
Cybernetics and Organizational Cybernetics
Science of Complexity
System Dynamics Methodology

The instructors have some choices in Part II. It may be a good idea to cover self-organizing and autonomous systems. These topics are important in complexity analysis and complexity management. The material will establish a good background for students so that they can follow the methodologies mentioned in this part without too much difficulty. Beer's VSM is an important methodology for those who will be involved in organizational issues and organizational design. As mentioned earlier, Science of Complexity includes the topics biological organization, computer mathematics, physics, parallel network computing, non-linear system dynamics, chaos theory, neural networks and connectionism. The importance of this material should not be underestimated; it will show students how organizations behave like biological systems and they update and reorganize themselves to survive. However, the instructor is reminded again that it is quite challenging to learn and apply this methodology.

System Dynamics Methodology will motivate students in learning and applying the following important concepts: problem structuring, resources, relationships, people, worldviews, goals and aims, controls, structures and processes. Students will appreciate that good problem structuring requires good system boundary selection. This will then help them to fix the system scope and focus on the relevant analysis. Furthermore, System Dynamics will make it easier for the analyst to develop a holistic perspective and see the unplanned and counterintuitive outcomes and their consequences. The methodology will also improve their feel for system models. Students will appreciate the differences between discrete and continuous systems, deterministic and stochastic models, and linear and non-linear systems. Also, they will develop a good understanding of some other important concepts, such as closed/open systems, feed-forward/feedback loops, open-loop/closed-loop control mechanisms, transient/steady-state behavior, emergent behavior, system hierarchies and system response lags. Lastly, System Dynamics will provide the analyst the opportunity to test some ideas through simulation and conduct what-if-analysis, which is certainly "the-must-have" tool for a decision maker. As long as it is applied with some care, System Dynamics can be a valuable tool in complex system studies.

Conclusions

The discussion developed in this paper examined a systems perspective of complexity analysis and management, and developed some suggestions for teaching the subject matter at the university level. The suggestions were grouped in two parts. The material suggested in the first part constitutes the background material; the contents are fairly standard. The second part examined the use of Organizational Cybernetics, Science of Complexity and System Dynamics in complexity analysis and management. It is hoped that the suggestions will guide the instructor to design effective courses on complexity management. The discussion provided in the paper is limited both in scope and depth. Only three system methodologies were examined and their use in complexity management was elaborated. Furthermore, the work is also limited in depth due to space availability. The contents of the second part are controversial and may be redesigned by considering the other system methodologies left out. Development of different arrangements for the second part will be the research topic of the future work.

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