

Complexity Decision Making and General Systems Theory: An Educational Perspective

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Abstract

The aim of this paper is to look at some important educational aspects of complexity decision making in a multidisciplinary manner from the perspective of General Systems Theory (GST). First, the major issues involved in complexity management and decision making are summarized as they are viewed in literature, and a review of GST and Systems Thinking is given. The discussion in the paper is developed within the context of GST in general, but concentrated on decision making in the three trends of GST: Operations Research, Cybernetics, and Managerial Cybernetics. Here, the role of Cybernetics in complexity decision making is particularly emphasized. The discussion is then extended to the latest developments in complexity decision making in Science of Complexity and Soft Systems Thinking. The study also includes a framework which is expected to guide instructors who are planning to offer contemporary courses on decision making. The framework provides some clues for assessing the level of complexity for a given situation and selecting the appropriate methodology for solution development.

Keywords

Complexity decision making, General Systems Theory (GST), cybernetics, science of complexity, soft systems thinking

In the past, decision making was generally viewed and taught within the conventional OR/MS (Operations Research/Management Science) paradigm (Daellenbach, McNickle, and Dye 2012). The reader can also see applications of Systems Theory to socio-technical systems in the “classical” work of Luenberger (1979). This paradigm is one of the trends in General Systems Theory (GST), and known to belong to the group of “hard” methodologies since it is based on mathematical tools. Methodologies in this group are suitable for solving structured problems, but they prove to be inadequate in complex situations. As systems become more complex, managing them and designing relevant decision making processes become more challenging. The view that managerial and decision making processes are influenced by organizational structure and culture and personal

inclinations of managers is a generally accepted fact. Different managers may have different goals and preferences, and all actors involved in decision making may have different perceptions of events. Furthermore, problematic situations in contemporary organizations, particularly at the top management level, have to be handled with incomplete, uncertain, and even distorted information in many cases. The complexity gets worse if there are rapid changes in the internal and external dynamics of the organization; organizations have to adapt to this environment in order to survive and grow. Considering all these

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aspects, one can say that systems-based approaches to complexity decision making appear to be more promising. They enable the decision makers the opportunity to address the problematic situation in its full system context.

Complexity and management of large-scale systems are central concepts in systems movement. As a matter of fact, some system methodologies have been specially developed to handle complex situations and large scale systems. It is no surprise that some researchers trace the roots of “modern complexity” to the birth of GST (Gorzen-Mitka and Okreglicka 2014). GST is known to be the “theory of all theories” or a “metatheory”, standing above all other theories. It involves systems of all sizes from a cell to the universe. By cutting across many disciplines, it complements the traditional scientific paradigm; it provides a holistic outlook to systems and complexity.

The major trends in GST are as follows: General Systems Thinking; Systems Approach; System Analysis; Operations Research (OR); Systems Engineering (including Cognitive Systems Engineering); System Dynamics; System Design; Teleology; Science of Complexity; Cybernetics; and Bionics (Skyttner 2001; Skyttner 2006). Complexity and large scale systems are major concerns in all these methodologies; the way they approach and seek solutions to problematic situations is complementary rather than competitive. The choice of the appropriate methodology is by no means easy. This question will be addressed in the coming sections of this paper.

There are quite number of research studies published on systems-based approach to complexity decision making. Pagani and Otto (2013) adopted qualitative mapping theory building and quantitative group model building approaches in a computer-based system modeling environment for market strategy development. They believe that this holistic approach enhances the quality of decision making processes. Carlman, Grönlund, and Longueville (2015) created a decision making process to establish communication

and collaboration between a technical-scientific group and social scientists for sustainability studies in ecological systems. Swami (2013), interestingly enough, included theories and concepts from psychology, behavioral economics, operations research, and managerial practice, in a holistic manner, and viewed decision making as cognitive processes of an executive function to be regulated and controlled. A new systems thinking-based framework was developed by Schiuma, Carlucci, and Sole (2012) where knowledge assets are translated into organizational values for decision making. A similar framework was developed by Wiek and Walter (2009), called the Transdisciplinary Integrated Planning and Synthesis (TIPS), which is mainly based on soft OR methods. This framework makes use of a multi-methodological approach, involving cognitive skills and habits of the stakeholders and experts, and their mutual and joint transdisciplinary learning processes. The framework was applied to a large-scale regional planning process in Switzerland. The results are yet to be seen.

Spencer (2014), on the other hand, viewed industrial complexity as a concept of emerging properties in the business world and suggested that managers can manage complexity by finding leverages in known cause-effect relationships, or by building interfaces and deconstructing complexity. He believes that this holistic approach is expected to yield better results than the traditional reductionism in which economies of scale and opportunities for synergetic innovation are lost. Gorzen-Mitka and Okreglicka (2014) argued that strategic decision-making in complex environments requires meta-cognitive skills which provide leaders with a toolbag for innovative and adaptable decision models beyond linear thinking. Here, the inclusion of cognitive aspects of decision making explicitly is quite significant, in addition to the emphasis put on the nonlinear nature of the processes involved. Elsayah et al. (2015) handled complexity by integrating qualitative information into formal simulation models in a complex viticulture irrigation

management system in South Australia. The models they developed involve cognitive mapping; they also suggest that the resulting structure is innovative and captures the richness of decision making and mental models.

The idea that hard OR/MS paradigm needs to be complemented by soft system approaches is shared widely in literature. For instance, Mingers examined the subject matter and developed a comprehensive and interesting discussion (Mingers and White 2010; Mingers 2011; Mingers 2015). Some others, including Jamali (2005), Daellenbach et al. (2012) and Yurtseven and Buchanan (2016), discussed complexity decision making within the university education context. The common theme in these studies is that educating students with a holistic outlook broadens their vision and helps them to become more successful professionals. If we look at engineering graduates, we realize that quite a significant portion of them perform engineering management type of work, particularly in the latter part of their careers. It is well-known that they generally find it difficult to integrate into multidisciplinary teams; they have a technical outlook to work, lacking a systems view. The hard approaches they learn at the university are insufficient for handling complex situations. In contrast, soft methodologies cover a wide range of approaches that hard methodologies cannot capture (Maani and Cavana 2007; Mingers and White 2010; Mingers 2011; Petkov et al. 2007; Yurtseven et al. 2013).

The ideas put forward above can certainly be extended to other areas; the case of OR/MS paradigm is nothing but a microcosm of the present university curricula in engineering or business administration. All human activity systems are socio-technical in nature, and they should be treated as such. Hence, students should be taught how to approach complex systems and how to make use of both hard and soft tools in the analysis and design of human activity systems. The interested readers should see Mingers

and White (2010), Mingers (2011), and Yurtseven and Buchanan (2016) for detailed discussions of this subject.

The rest of the paper is organized as follows: The major issues in complexity management and complexity decision making are given in the next section. This is followed by sections on general aspects of complexity and decision making, an overview of GST and complexity decision making from a GST perspective. The last two sections include methodology selection and problem structuring, and a description of the framework developed, respectively.

COMPLEXITY MANAGEMENT AND DECISION MAKING

Most of the existing management models are built on the assumption that socio-economic structures are in equilibrium and that they are stable. However, It is getting harder to predict the future developments in highly complex, volatile, and dynamic situations via these models. In the contemporary world, many companies find themselves in complex and non-linear environments which require non-hierarchical organizational structures and decentralized operations. It is no longer realistic to rely on the conventional decision-making models that are based on linear processes. Pellissier (2012) argued that contemporary decision making models ought to be designed in complexity domain, not in a linear domain. He also suggests that the new knowledge-based socio-economic structures should be built on the complexities of the present world business. An interesting approach of this kind was reported by Paul et al. (2014) where researchers made use of concepts observed in bee populations. The decision making models they built were based on emergent properties of complex systems of bees as they share information, learn, memorize, reproduce, etc. during their foraging activities. The reader should note that similar models are also used in solving problems such as large scale precise navigation,

managing telecommunication systems, economic power dispatch, water resource management, etc.

The significance of modeling emergent properties of complex systems is also emphasized by Li et al. (2009), as it is in Paul et al. (2014). This study investigates the general principles involved in the evolution of Supply Networks (SNs), and presents a Complex Adaptive Systems (CAS) model that formulates supply chain dynamics. SNs are complex networks of organizations that synchronize a series of inter-related business processes, such as procurement, manufacturing, and distribution, and the entities in the SNs operate subject to their own local strategies, constraints, and objectives. The fitness landscape theory is used to represent the dynamic interaction among firms and the environment; the emergence of cooperation networks is viewed as an endogenous process driven by the complex and dynamic interplay among institutions, products, technologies, markets and innovative actors. The resulting evolutionary model represents a multi-agent system, with self-organization processes, and allows the identification of the salient factors that control evolution. The model was simulated and its dynamic behavior was analyzed from a variety of organizational perspectives.

Complex systems are usually large and they have a number of subsystems with complex relationships, all operating simultaneously. They have non-linear and stochastic processes with feedback loops and time delays. These aspects usually obscure the cause-effect relationships, making the decision hierarchy design difficult (Ivanov, Sokolov, and Kaeschel 2010). Poorly taken decisions, based on poor models, may sometimes yield the opposite of intentions, or they may not be valid in the long term even if they are successful in the short term. Also, as a result of strong nonlinearities and human intervention, the organization may move toward unwanted states, sometimes irreversibly if the decision mechanisms are not well designed. This is why adaptive organizational structures, in particular systems with self-organization

and evolutionary properties are important in managing complexities like global financial crisis, natural disasters, environmental problems, the impact of information technologies on societies, etc.

A thought provoking theoretical assessment of complex systems was reported by Arévalo and Espinosa (2015). According to them, complex systems are primarily investigated in Sciences of Complexity, CAS, and Cybernetics. The former two are mainly concerned with natural and artificial complex systems, whereas Cybernetics or Organizational Cybernetics tends to look at self-organization in businesses and social organizations. Organizational Cybernetics is better suited for understanding structural complexity as demonstrated by Beer's viable system; Complexity Sciences and CAS are popular methodologies in studying complexities of ant colonies, internet, informatics viruses, etc. The common theme seen here is that self-organizing systems are basically nonlinear that evolve over time, exhibiting emergent properties as a result of interaction between autonomous agents. Arévalo and Espinosa (2015) also noted that there are hardly any analytical models available for guidance; only some metaphoric and simulation studies can be found in literature. Another theoretical approach, equally interesting, was reported by Lord, Dinh, and Hoffman (2015). The authors provide an organizational theory from the perspective of quantum mechanics and study organizational change. They suggest that the prevailing perspectives on time and change mostly consider the relative stability of attributes; organizational evolution is based on a linear progression of past that moves to the present, and then to the future. They think that viewing time and change from quantum mechanics and quantum probability allows one to see the uncertainty of emerging organizational phenomena, which otherwise is being obscured. They developed a framework in the paper, explaining "How organizations (or societies) can experience unforeseen potentialities that radically change their development by conceptualizing the

future as existing in a state of potentiality that collapses to form the present based on the dynamics of system constraints". The authors claim that these conclusions have broad implications beyond organizational change.

There are a number of studies in literature where complexity management and decision making are handled in a practical manner. Kluth et al. (2014) discussed these approaches in detail. They classify the simplest approaches available as "trial and error" or fading out the complexity of the problem. The more advanced approaches are listed as follows:

(1) "Intuitive review" (reduction of complexity by pattern creation on the basis of acquired knowledge and using diversity of knowledge from heterogeneous groups);

(2) "Rational understanding" (understanding in detail by prioritizing the level of detail in terms of 80/20 rule);

(3) "Focusing on individual factors" (trivialization by dividing the main complex problem into single minor problems). It seems that the choice of the approach will depend on the situation and the designers' preferences.

Chronéer and Bergquist (2012) discussed managerial complexity issues in a more specific area, namely in Swedish process R&D (research and development) projects. They argue that cross-functional teams, globalization, shorter product life cycles (such as round-the-clock production), and costly and specialized characteristics of process industry are the major factors that create complexity. Furthermore, they say, special tasks and uncertainty of R&D and innovation processes add additional complexities. The conceptual model given in the paper shows competence areas a project manager must have. It appears that managers should be able to integrate production and product competences, and also acquire customer processes. Beaudin and Zareipour (2015) looked at complexities involved in different aspects of residential energy management. They state that while

some of the diverse modeling approaches may exist for finding new methods for improving energy scheduling in residential settings, measures of complexity and tractability must also be included in the modeling procedure. This, they say, will provide the opportunity to make a fair comparison of the trade-offs between optimal scheduling and computational considerations.

Another interesting application was reported by Kardes et al. (2013). They conducted an exploratory research on managing complexity and risk in global megaprojects, and examined factors that contribute to success. Megaprojects are usually formulated in high-pressure, competitive, and complex environments where the rate of failure is high. The study offers a risk management framework and managerial prescriptions for enhancing success in an area which did not receive enough attention in the past. The study conducted by Ahmadi et al. (2015) had a strong socio-technical flavor; they developed a new structural approach for managing readiness-relevant activities in the implementation of ERP (Enterprise Resource Planning) systems. Unlike the available approaches, they identified the dimensions of readiness as organizational, social, and technical. They suggest that their approach ensures the overall readiness of an organization for such large scale projects.

GENERAL SYSTEMS THEORY (GST) AND SYSTEMS THINKING: AN OVERVIEW

The origins of GST can be traced to Bertalanffy's work in microbiology in the late 1920s when he realized that it was not possible to understand the behavior of a microorganism without looking at the whole it belongs to. However, GST was not formally developed until 1954; International Society for General Systems Theory was founded then, led by Ludwig von Bertalanffy and Kenneth Boulding. GST was developed in later years, gradually, eventually

adopting the following goals: (1) To formulate generalized systems theories including theories of systems dynamics, goal-oriented behavior, historical development, and control processes; (2) To work out a methodological way of describing the functioning and behavior of systems objects; (3) To elaborate generalized models of systems (Skyttner 2001; Skyttner 2005). The assumption was that all kinds of systems (concrete, conceptual, abstract, natural, and man-made) had common characteristics. Consequently, GST is said to be a theory cutting across many disciplines. Different types of systems are classified, ranking in increasing order of complexity, each level including lower levels with its own emergent properties. At each level, system's behavior is determined by the relationship between system components, not only by the nature of individual components.

GST incorporates the subjectivity issue in system studies with concepts of intervention, activism, and participation, and deals with processes such as life, death, birth, evolution, adaptation, learning, motivation, and interaction. This means that it is also possible to take emotional, mental, and intuitive concepts into account as a part of reality. In this respect, GST questions the foundations of the traditional scientific paradigm. As it is known, non-intervention, neutrality, and objectivity are the cornerstones of the traditional scientific paradigm. They are viewed as meaningless in quantum theory, hence in GST. These three concepts are seen as nothing but an "illusion" since the observer is a part of the system; she/he cannot get out of the system to be non-interventional, neutral, and objective.

GST is generally considered to be successful although it does not provide detailed methodologies applicable to specific fields. There are some widely-known laws, principles, theories, and hypothesis in GST (Skyttner 2001; Skyttner 2005). The darkness principle is one of the important principles; it states that no system can be known

completely. Hence, we should never expect to know complex systems completely. The complementary law states that any two different perspectives (or models) about a system will reveal truths regarding system that are neither entirely independent nor entirely compatible. This suggests that different people may view "reality" from different perspectives, hence modeling and control system design should be conducted in a pluralistic environment. The Law of Requisite Variety states that control can be obtained only if the variety of the controller is at least as great as the variety of the situation to be controlled. The Law of Requisite Hierarchy says that the weaker and more uncertain the regulating capability is, the more hierarchy is needed in the organization of regulation and control to get the same result. The readers should note that these laws and the principles have important implications for organizational design, management, and handling complexity.

What is known as System Science is the applied form of GST; it is a meta-discipline where system models and models' behavior are transferred from one discipline to the other. Computer is similar to the laboratory of classical science where analysis and design of complex systems are conducted through calculations, simulations, and the creation of non-existing reality. This, of course, enables systems designers to handle considerable complexity without too much difficulty. Simulations offer the advantages of modeling complex system characteristics that cannot be handled analytically or by any other approach.

Cybernetics was established by Wiener in 1948 and it is one of the strands in GST. It involves the study of living systems through analogy with physical systems by interpreting feedback theory and control, self-regulation, and automation. Philosophically speaking, this is a constructivist view of the world objectivity derived from shared agreement about meaning. Accordingly, the world is invented in a social tradition, which implies that information or intelligence is an attribute of an interaction rather than

a commodity stored in computer memory. Control and communication are thought to be closely interrelated processes where control involves: (1) information processing; (2) programming; (3) decision; and (4) communication. The aim of control in Cybernetics is to achieve a condition of equilibrium within the system and between the system and its environment, and keep the system in this equilibrium state. The programming levels for process control in a Cybernetic system are: (1) DNA and genetically level; (2) the brain with its cultural programming; (3) the organization with its formal decision procedure; (4) mechanical and electronic artifacts with their algorithms (Skyttner 2001; Skyttner 2005).

Organizational Cybernetics or Managerial Cybernetics is an area where cybernetic principles are used to understand organizational complexities and design organizations. In particular, the Viable System Model (VSM) developed by Beer views an organization as a living organism with a brain rather than a static system as suggested by organizational charts; it is seen as a significant approach in organizational design (Jackson 2003).

Systems Engineering (SE) is another trend in GST, and it is an important area of application of Systems Science and Systems Thinking. The life-cycle methodology of SE enables designers to design highly complex systems in many areas, such as manufacturing industry, service industry, defense industry, information systems, health care facilities, etc. Hitchins (2003) viewed systems engineering as follows: “a distinct discipline, founded on a system-scientific basis, including systems theory, systems thinking, systems engineering and systems management in a single framework”. He suggests that “systems engineering will expand its horizons to encompass all kinds and types of systems, including business, industry, socio-economic, governmental, and ecological”. INCOSE proposes similar ideas in its *Systems Engineering Vision 2020* document as follows (INCOSE 2007): “The projected state of MBSE

(authors’ note: MBSE stands for Model-Based Systems Engineering) practice in 2020 will extend MBSE to modeling domains beyond engineering models to support complex predictive and effects-based modeling. This will include the integration of engineering models with scientific and phenomenology models, social, economic, and political models and human behavioral models”. The readers can find many references on SE, including Parnell, Driscoll, and Henderson (2008), Hitchins (2003), Sage and Armstrong Jr. (2000), Kossiakoff and Sweet (2003), and Caddy and Helou (2007).

Related to SE, Cognitive Systems Engineering (CSE) was developed as a significant trend in GST in the last decades. In CSE, complex human-machine systems are viewed as socio-technical constructs. According to Hollnagel and Woods (2005), CSE was formulated in the 1980s as a proposal to overcome the limitations of the conventional Information Processing Systems (IPS) paradigm. In CSE, the focus is on how system parts communicate with each other. The Joint Cognitive Systems (JCS) paradigm, developed by Hollnagel and Woods (2005), tends to focus on how the joint system performs as a whole. Rasmussen, Pejtersen, and Goodstein (1994) suggested that CSE is a powerful approach for human-machine system design, and it is applicable across a spectrum of single machine systems, socio-technical systems, and whole organizations, ranging from process and manufacturing industries to military and service systems.

According to Hollnagel and Woods (2005), one has two choices in human-machine system design process: Designing for Simplicity or Designing for Complexity. The former is based on reducing the demands on tasks or increasing the system or controller capacity, or doing both. Although it seems it is possible to handle the growing system complexity this way, the resulting system will have a built-in limitation. The limitation is due to what is known as the n+1 fallacy: If the system is designed to handle n

number of possible states, there is always the state $n+1$ that has not been accounted for. Designing for Complexity, on the other hand, states that complexity cannot be reduced to an arbitrary low level. In other words, the Law of Requisite Variety should be satisfied; the controller or operator should have at least as much variety as the system to be controlled. Since the designer cannot reduce the requisite variety through interface design, she/he has no choice but to increase the variety of the controller. The resulting system is very likely to perform better since complexity of the reality is acknowledged rather than simplified. Hollnagel and Woods summarized their argument as follows: “rather than designing for a simple world that does not exist, the goal should be to design for the complex world that does exist” (Hollnagel and Woods 2005).

OR is the first formal system methodology. It emerged during World War II in Britain while complex military strategic decisions, resource allocations, optimal scheduling, and risk analysis were being resolved. OR is known to be a successful methodology primarily at the tactical level, but not at the strategic level where problems are unstructured. In fact, all hard system thinking approaches have serious limitations when it comes to handling messy or unstructured problems (Checkland 1993; Checkland and Scholes 1990; Daellenbach et al. 2012). In addition to OR, the classical versions of System Analysis, Systems Engineering, System Dynamics, and Cybernetics are the main strands in this category. The common theme in all of these approaches is the belief that any problem can be solved by setting objectives and then finding from a range of alternatives the one solution that will be optimal in satisfying these objectives via the use of hard data and hard tools. This means-end, objective-seeking approach has been found inappropriate by some systems thinkers since ends and means can be problematic themselves. For instance, conflict in strategies, decisions, and the means of achieving them

lead to a new set of issues to be managed. As a matter of fact, this is the main reason behind the emergence of Soft Systems Thinking.

Soft Systems Methodology (SSM), a well-known methodology, was developed by a team headed by Checkland at University of Lancaster, UK. It is known to be a successful methodology, in general (Checkland 1993; Checkland and Scholes 1990; Daellenbach et al. 2012; Maani and Cavana 2007). SSM embraces a paradigm of learning rather than viewing the world as systems whose performance can be optimized by following systematic procedures. It acknowledges that there can be different perceptions of a situation or reality, leading to different viewpoints, and eventually to different solutions. Senge’s Systems Thinking, Soft OR, Soft System Dynamics, Cognitive Mapping, SODA (Strategic Options Development and Analysis), and Soft Cybernetics are the other well-known methodologies in Soft Systems Thinking.

System Dynamics (SD), another trend in GST, makes use of control theory concepts, such as feedback regulation, etc., in modeling, analyzing, and designing socio-economic systems. Developed by Jay Forrester in 1969, it is closely related to Systems Theory; its basis is a scientific paradigm, a set of computer tools, and computer simulation-based models which helps to explain the forces of dynamics that underlie change and complexity in business, political, social, economic, and environmental systems. SD embraces many ideas from the soft systems school, particularly Senge’s Systems Thinking. Developments in methodology and computer technology made SD quite a popular approach in industry. It is now possible to combine hard and soft modeling approaches in SD, via applications software packages such as Stella. Highly complex systems in diverse areas like supply chains, ecological systems, and health-care systems can be modeled, simulated, analyzed, and designed using SD with some ease (Daellenbach et al. 2012; Maani and Cavana 2007; Weil 2007; Lyneis and Ford 2007; Sterman 2000;

Yurtseven and Buchanan 2013). The readers should note that there are some challenging applications in literature, sociology, psychology, and history—One of them is on modeling and analysis of “Hamlet’s hatred”.

COMPLEXITY DECISION MAKING: A GENERAL SYSTEMS THEORY (GST) PERSPECTIVE

It is common knowledge that there are rapid changes in business environment due to technological advances and globalization. In this new volatile environment, the organizational structures designed for relatively stable environments are becoming almost obsolete in many sectors. In response to this change, companies are creating new and more flexible organizations to produce unconventional solutions. Obviously, change is not a new concept; it has been there since the beginning of time. If we need understand the theoretical foundations of change, we will be then in a better position to deal with the complexity it generates. One of the early works on the theoretical basis of complexity was carried out by Wiener in his work on Cybernetics (Skyttner 2001; Skyttner 2005). Wiener suggested that understanding the relationships between feedback processes operating at the deep structural level can help us to determine the system behavior at the surface level. In Organizational Cybernetics, systems behavior is based on underlying principles of structure, in parallel to traditional Cybernetics. If we look at Beer’s VSM, we see that the operation of a complex organization is similar to the model of a living organism. Through the use of VSM, it is possible to model a subsystem like a department in an organization, or the supra-system (the system of which the organization is a part); it has the ability to reconfigure itself, just like a living organism, if its environment changes. VSM allows us to understand the complexity of the organizational structure, the degree of centralization/decentralization.

We can also analyze the organization’s stability, control, and coordination characteristics, and eventually we can redesign it.

Complexity issue was also studied by other important names in systems movement, such as Churchman, Ackoff, Weinberg, Forrester, and Gigch (Skyttner 2001; Skyttner 2005). Over the last decades, Science of Complexity emerged as a new paradigm in GST. It is a multi-disciplinary area, including biological organization, computer mathematics, physics, parallel network computing, non-linear system dynamics, chaos theory, neural networks, and connectionism. The primary aim in this paradigm is to try to describe the laws of complexity and understand how they generate much of the natural world and its emergent properties. Particularly, it is important to understand the conditions under which evolutionary, self-organizing, and self-complicating behavior emerges. Snyder (2013) pointed out those researchers at the Santa Fe Institute attempted to unify some of the core system concepts into a model known as CAS, which still is an evolving construct. It is argued that emergent properties of complex systems can be modeled and operated relatively more effectively as CAS (Marchi, Erdmann, and Rodriguez 2014; Paul et al. 2014). For instance, when managing a supply chain via CAS, analyst has the chance to model the emergent properties of the chain; emergent properties cannot be modeled explicitly by other approaches. It is suggested that this is the main reason why modeling and management of a supply chain via CAS has the potential to give better results (Caddy and Helou 2007).

Self-organizing and autonomous systems are also important in complexity management. These systems are studied extensively 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 seems to stop. Evolution creates individuals

who are relatively more independent of the environment with greater autonomy. The resulting rise in the level of consciousness generates more complex collective superstructures or ecosystems. Similar to species, industries and corporations respond to changing technological development and try to survive through self-organization. Similar phenomenon can be observed in stock markets, traffic flow, urban developments, social behavior of termites, weather conditions, etc. Studying self-organization and evolution helps us to understand how systems emerge from unstructured aggregates of components, and how variation and selection take place at different levels and between different co-evolving systems in nature. The theoretical findings are then used to design better social organizations; instead of looking for main causes to build centralized control, now we have the choice of designing systems that govern themselves.

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 central controller. For CAS, theory of self-organization arises from the adaptive capacity of the system to changing environmental conditions (Arévalo and Espinosa 2015). The readers should note that the brief discussion given above indicates that there is a strong theoretical framework in GST for handling complexity and complexity decision making issues.

Knowledge management is playing an increasingly important role in many areas, including decision making. Both knowledge management and organizational learning are human social systems, or complex adaptive systems (Kong 2003). “New Knowledge Management” is the second generation of managing knowledge, and it is based on holistic

thinking. The major difficulty in knowledge management appears to be relating human attributes to decision attributes; this difficulty makes decision-making process complex. Most Decision Support Systems (DSS) focus on the analysis and evaluation of alternatives within decision situations without integrating human needs and preferences. There seems to be an increasing demand for more specific and individually designed systems that address the real needs of decision makers and adapt to their specific mind-sets and decision-making styles (Kong 2003). For instance, decision-making in product development represents a complex process which can involve many different stakeholders with different perspectives (technical, strategic, and organizational), decision-making styles, educational backgrounds, level of knowledge and experience (novice or expert), and mind-sets of decision makers.

The complexity involved in integrating human attributes into a DSS is generally handled within CSE or sometimes under Human-Centered Design (HCD), User-Centered Design (UCD), Cognitive Engineering (CE), Human-Computer Interaction (HCI), and Human-Systems Integration (HSI)) (Ölmez and Lindemann 2014). The interested readers should also see Righi and Saurin (2015) for an ergonomic perspective of managing complex socio-technical systems.

Intelligent technology and techniques (expert systems, fuzzy logic, machine learning, neural networks, and genetic algorithms) offer better opportunities for knowledge management, hence for decision making (Ngai et al. 2014). They can be very useful in overcoming some of the difficulties mentioned above by facilitating learning. The resulting DSS tends to be more complex with the ability to create and manage knowledge, and add value to products and services. They can be employed to support complex decision making at different levels in an organization, particularly at the strategic level through Executive Support Systems (EES) or Group

Decision-Support Systems (GDSS) (Khan 2014). In the contemporary world, managers often do not have the time to go through the classical management model (planning, organizing, coordinating, deciding, and controlling), but need to produce fast and effective decisions quickly. This is where new technologies and techniques, particularly business intelligence, business analytics, and intelligent DSS become critically important. They provide correct and nearly real-time information and give valuable support in rapid decision making. In conclusion, organizational learning, intelligent knowledge management, and intelligent decision support systems provide us the opportunity to design self-organizing and regulating decision making systems. The interested readers will find a variety of related models/methods/systems for sustainable system development, decision-making, environmental impact assessment, life cycle assessment, ecological footprints, cost benefit analysis, etc. in Elsawah et al. (2015), Carlman et al. (2014), and Schiuma et al. (2012). Kluth et al. (2014) reminded us that, despite all these developments, many companies do not seem to have access to adequate tools for complexity management.

METHODOLOGY SELECTION AND PROBLEM STRUCTURING

Selection of the appropriate methodology or methodologies for a problematic situation has been receiving an increasing attention in the last decades. Selection is becoming more of a challenge as systems become more complex, and the number of system methodologies increases as time goes on. One of the interesting studies on methodology-problem context was discussed by Kurtz and Snowden (2003). They developed what is known as the Cynefin sense-making framework, shown in Table 1. Here, systems are classified as Known, Knowable, Complex, and Chaos. The main characteristics of the

corresponding methodologies are also given in the framework. The Known systems are the systems that have perceivable and predictable cause-and-effect relationships. They can be handled by the rather simple Sense-Categorize-Respond type methodologies. A typical example for this category is process re-engineering where processes are redesigned to achieve a more efficient operation. In the Knowable category, cause and effect are separated over time and space, and Sense-Analyze-Respond type methodologies are suitable. For instance, supply chain cause-effect relationships have these characteristics, hence they can be modeled and managed effectively by the class of methodologies suitable to this category—SD belongs to this category (Maani and Cavana 2007). Complex systems, on the other hand, are viewed as systems with cause-and-effect relationships that are coherent in retrospect and do not repeat; apparently, the appropriate methodologies for this category are the Probe-Sense-Respond type. Pattern management can be given as an example for this category. In chaotic systems, cause-and-effect relationships are not perceivable and can be handled only by the Act-Sense-Respond approach. Here, one can only talk about management of the crisis; nothing more than that. Complex decision-making situations that fall into the domain of this paper belong to the Knowable and Complex systems categories. Hence, Sense-Analyze-Respond and Probe-Sense-Respond type methodologies are needed to resolve complex decision-making situations. It should be noted that, although the boundaries between different categories are somewhat hazy, the framework provides useful clues for methodology selection.

A similar framework was developed by Jackson (2000; 2003). It is easier to follow Jackson's work if one is familiar with various systems approaches. In the framework, well-known system methodologies are related to problem context where the user needs to identify the type of the system studied and decide on the degree of complexity of the problem. There are six

Table 1. The Cynefin Sense-Making Framework

Complex Cause and effect is only coherent in retrospect and does not repeat Pattern management Perspective filters Complex adaptive systems Probe-Sense-Respond	Knowable Cause and effect separated over time and space Analytical/Reductionist Scenario planning Systems thinking Sense-Analyze-Respond
Chaos No cause and effect relationship perceivable Stability-focused intervention Enactment tools Crisis management Act-Sense-Respond	Known Cause and effect relations repeatable, perceivable and predictable Legitimate best practice Standard operating procedures Process re-engineering Sense-Categorize-Respond

ideal-type forms of combined “systems” and “participants” dimensions in the framework: simple-unitary, simple-pluralist, simple-coercive, complex-unitary, complex-pluralist, and complex-coercive. These are then related to the following systems approach categories: Functionalist Systems Approach; Interpretive Systems Approach; Emancipatory Systems Approach; Postmodern Systems Approach; Critical Systems Thinking. For instance, hard OR (and this is true, if to a lesser extent, for Systems Analysis and Systems Engineering) belongs to the simple-unitary group. In complex-unitary situations, the use of System Dynamics, Organizational Cybernetics, and Complexity Theory is suggested. Soft systems approaches are recommended in complex-pluralistic situations, and Critical Systems Thinking is suggested where a variety of methodologies, methods, and models can be employed simultaneously. The interested readers should also see Pownall (2012) where decision making models are classified, and classical, systems-based, and heuristic-based approaches are discussed in detail.

The weakness of the hard MS/OR methodology is its superficiality of understating of the system environment. Sometimes, the task is reduced “to fit the problem or technique by drawing questionable

boundaries”. This increases the risk of finding an elegant answer to the “wrong” problem. The major advantage of systems-based approach is to provide the hard MS/OR practitioner to step back and study the problem in its full system context, and judge whether the particular approach adopted is really the appropriate one. It is important to note that the weakness mentioned here is not limited to hard OR methodology; it is true for other hard approaches.

The following tools are available to help the modeler or designer in problem structuring: mind maps, rich picture diagrams, cognitive maps, causal-loop diagrams, influence diagrams, and decision flow diagrams (Daellenbach et al. 2012). The readers should note the significance of graphical modeling in problem structuring process. It is also important to remember that good problem structuring requires good system boundary selection and proper scope development. Poor boundary selection and poor scoping may lead to the solution of the “wrong” problem, producing serious consequences for the stakeholders.

Figure 1 and Figure 2 illustrate the differences between the traditional problem definition and the problem structuring processes, respectively (Daellenbach et al. 2012). The System S is created in “wider system

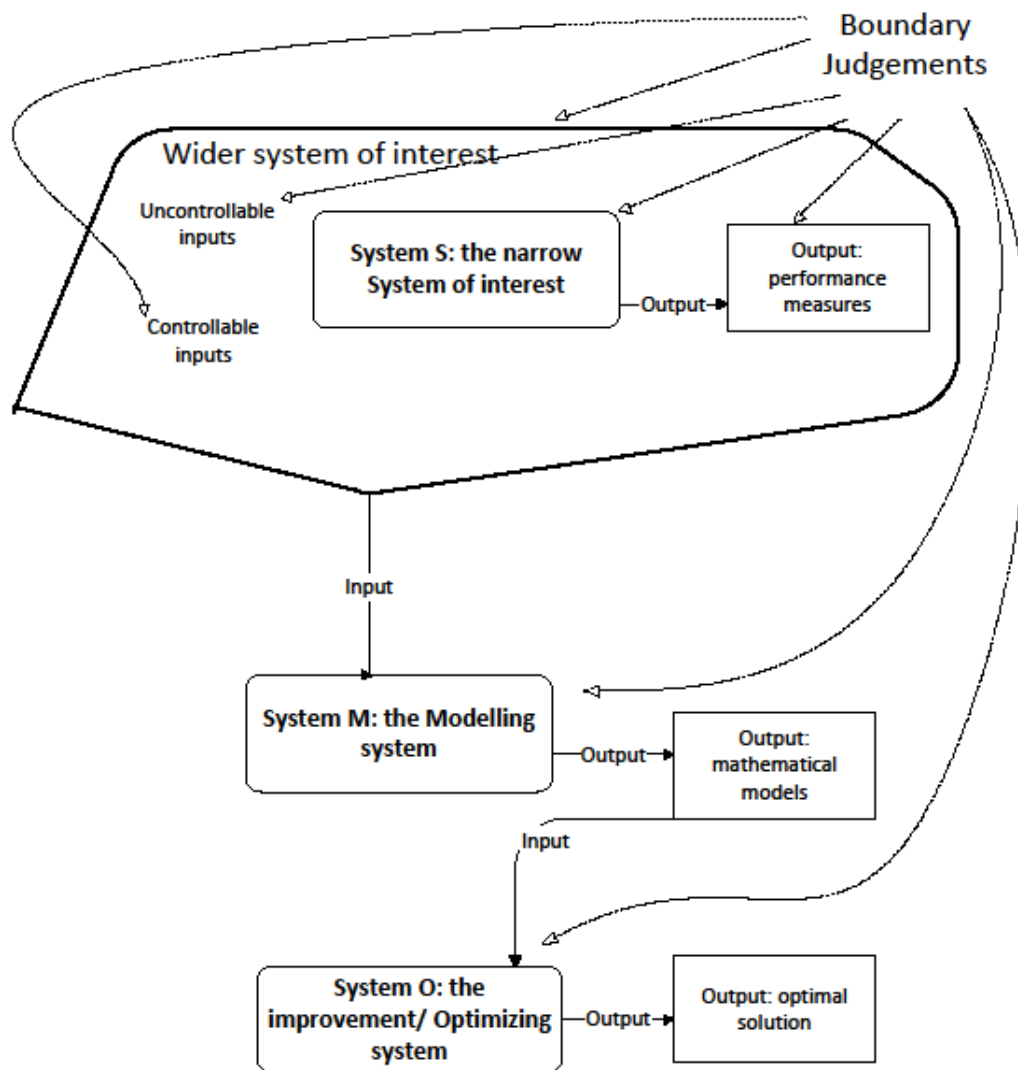


Figure 1. Structure Diagram for Hard OR Methodology (Daellenbach et al. 2012).

of interest” in the structure diagram for hard OR (see Figure 1). This then becomes the input to process of mathematical modeling System M. The output of the model is then fed as an input to System O where improvement/optimization calculations are performed. The readers should note that the output of System S is not fed into System M as an input directly in Figure 2; System S is developed within System M. The boundary judgments affect all aspects of the study as shown in both figures. While System S (the narrow

system of interest) and System M (the modeling system) are separate in the hard OR methodology, System S is defined within System M in the soft approach. The richness of the inputs used in the definition of System S is obvious; besides the boundary judgments, controllable and uncontrollable inputs, additional inputs (technology, facilitation, problem structuring, reflective thinking and commitment for action) are used in order to capture the problematic situation in its full system context.

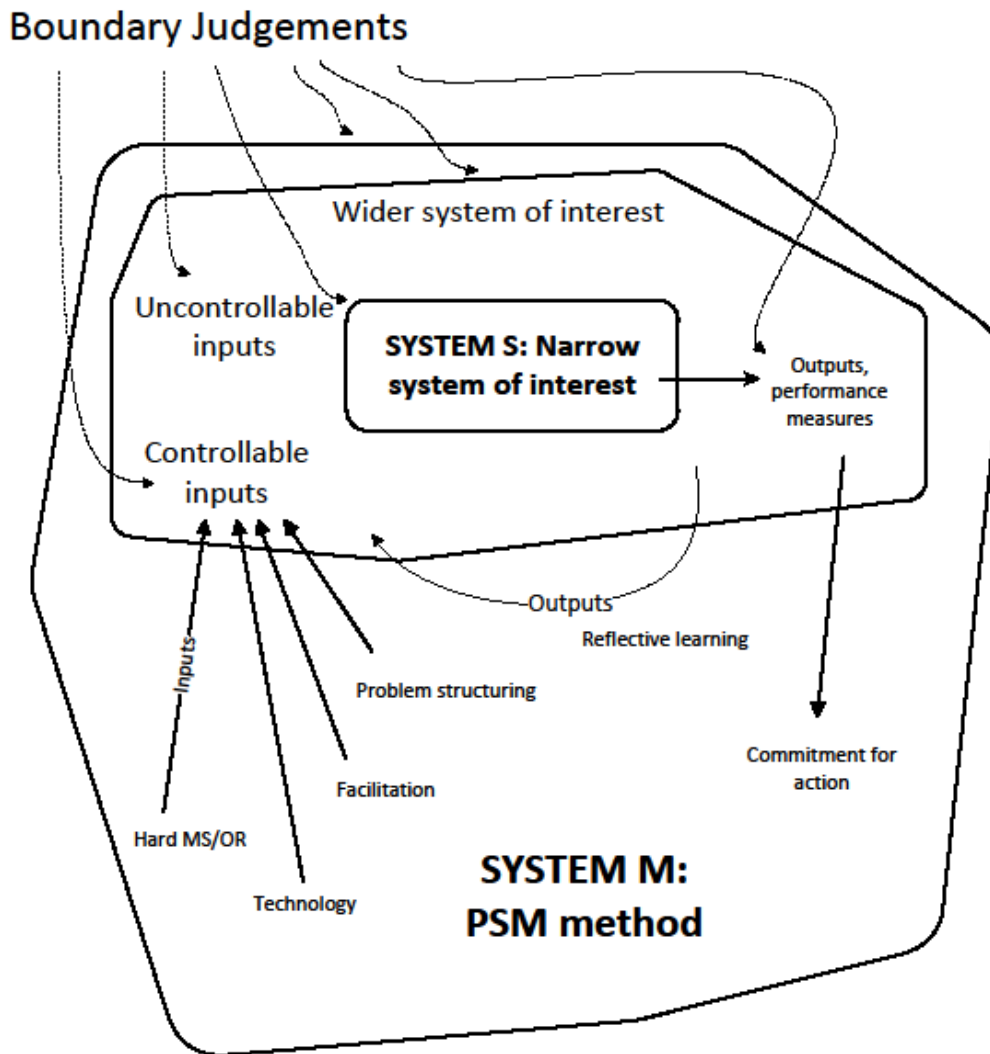


Figure 2. Structure Diagram for PSM (Problem Structuring Method via Systems Thinking) (Daellenbach et al. 2012).

THE FRAMEWORK PROPOSED

This framework is designed to guide instructors who are planning to teach “Decision Making in Complexity” in a multi-disciplinary manner. The framework is consisted of two parts: Part I: Background Material; Part II: Selected Topics in Complexity Decision Making.

Part I: Background Material

The aim in this section is to give overview of decision

making and holistic thinking (or systems thinking).

The major topics to be covered are:

- (1) Duality of Decision Making: Partly Art, Partly Science;
- (2) Different Concepts of Rationality;
- (3) Approaches to Decision Making: Qualitative Methods and Analysis; Quantitative Methods and Analysis; Holistic Decision Models; Heuristic Decision Making; Group Decision Making;
- (4) Introduction to Systems Thinking and GST:

Historical Developments in Systems Thinking; Basic Ideas of GST; Cybernetics and Concepts Defining Systems Processes; Organization Theory and Management Cybernetics; Complex Adaptive Systems; Science of Complexity; Self-organization and Evolution; Learning Organizations; Knowledge Management; Intelligent Decision Support Systems.

Part II: Selected Topics in Complexity Decision Making

(1) Decision Making and Decision Aids—A General Systems Perspective: Some Concepts and Distinctions of the Area; Basic Decision Aids; Managerial Problems and Needs; Decision Support Systems and Computer Support; Psychological Aspects of Decision Making;

(2) Soft Systems Thinking and Decision Making: Overview of Hard Systems Approaches and Hard OR Methodology; Fundamentals of Soft Systems Thinking; Issues in Methodology Selection;

(3) Basics of SSM and Soft OR; Problem Structuring Methods (PSMs); Systems Modeling via Combination of Hard and Soft Approaches; Simulation Models and System Simulation; Critical Systems Approaches; Meta-Methodologies; Modeling Complex Systems; Selected Case Studies in Complexity Decision Making.

The difficulty in teaching holistic decision models is the lack of explicit guides or rules to be followed in the application of soft systems approaches. Students will find it challenging to apply them since they are mostly used to the algorithmic nature of hard methodologies. Case studies can help students to develop a deeper understanding of complexity and resolve complex decision situations through soft thinking. It is unlikely that very specific rules and guidelines will ever be developed in soft approaches. However, it is expected that they will be refined as time goes on, making them more “applicable friendly”.

The major advantages of soft systems-based

methodologies become obvious in problem structuring, learning, conflict resolution, contingency planning, and problem solving. These advantages can be summarized as follows:

(1) The problem situation is described in a large context rather than in a narrowed down framework;

(2) A dialogue between different stakeholders is facilitated, helping to resolve conflicting perceptions and objectives;

(3) “What” types of questions are asked before “how” types; this is important since it guides the work team to explore problem in many dimensions before attempting to produce a solution;

(4) System analysts act like facilitators and resource persons, supporting stakeholders to resolve complex issues;

(5) Problem resolution is seen as a dynamic activity rather than static; stakeholder’s perceptions or some other parameters may change as work progresses, changing problem formulation;

(6) Human aspects of the problem situation are accounted for, explicitly.

In short, in contrast to the conventional approach, problem structuring allows the problematic situation to be assessed in many different dimensions, including people, relationships, world views, goals and aims, controls available, actions and reactions, uncertainties, conflicts, system structures and processes. The model developed can then serve as a basis for discussion and identify the significant system issues. Also, with this model, it becomes easier to see the relevant system environment and the stakeholders, to formulate the objectives and performance measures, to develop alternative courses of action, and to predict the unplanned and counterintuitive outcomes. Students will find it challenging to include soft indicators (such as morale, commitment, burnout, care for customers, and capacity for learning), together with hard indicators (such as key performance indicators or critical success factors), in the modeling and design process. They will also experience difficulty in

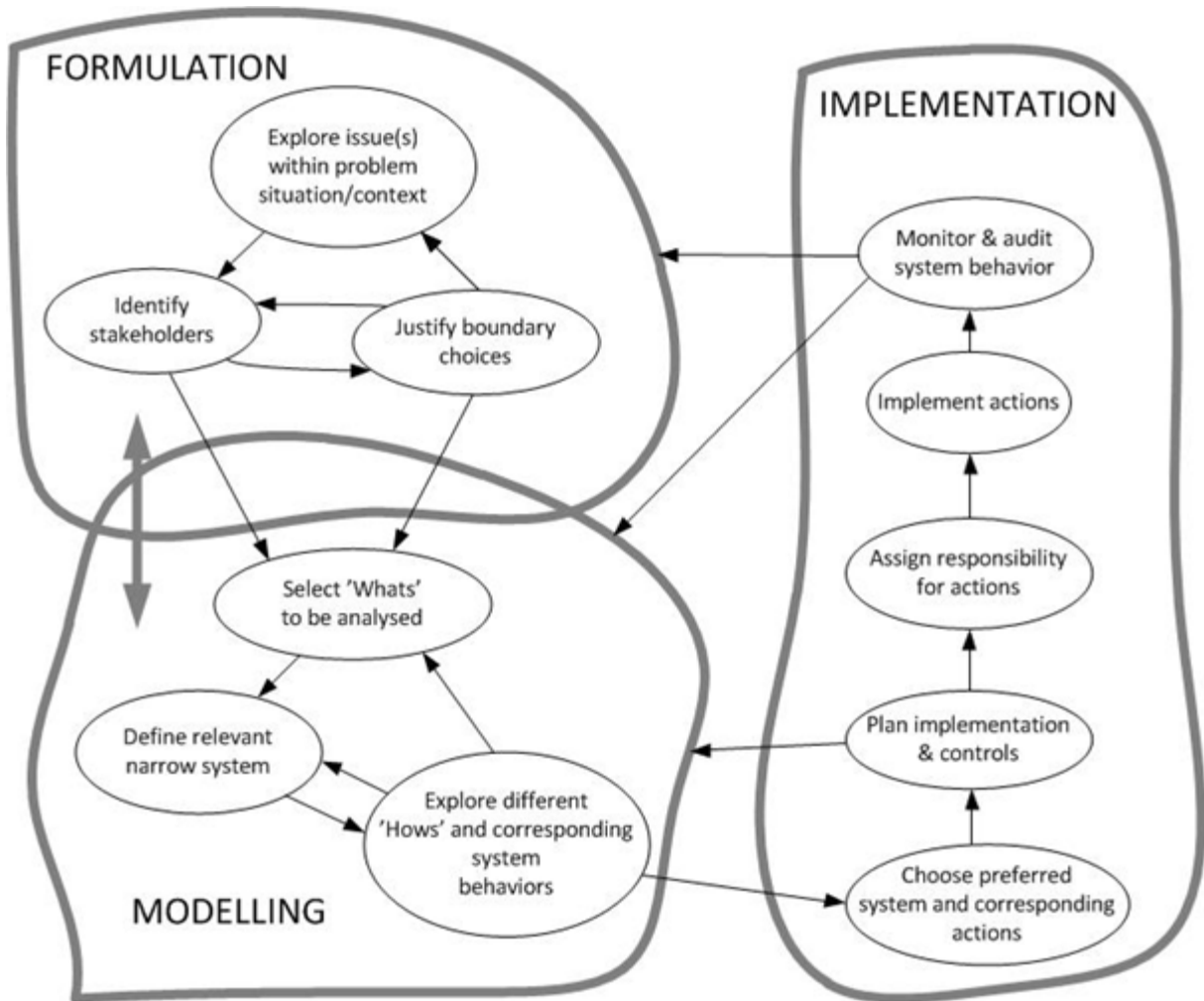


Figure 3. General Working Mode of PSMs.

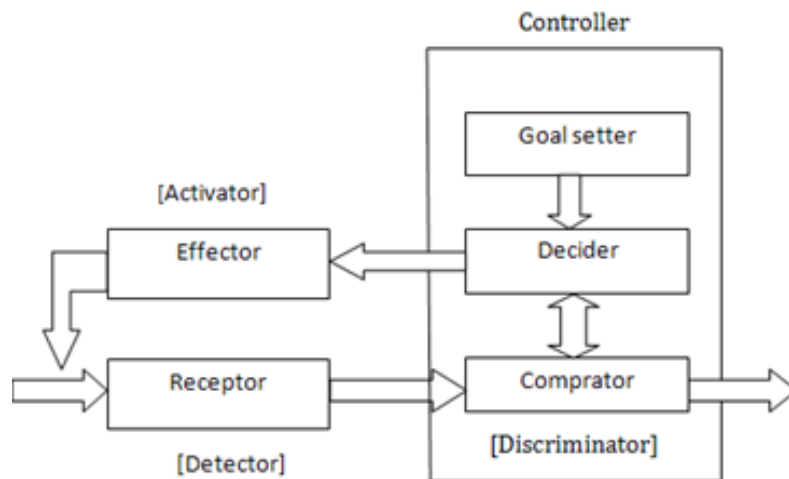


Figure 4. A General Control System.

mastering system simulation techniques. For interesting modeling and simulation studies, the readers are referred to Maani and Cavana (2007), Daellenbach et al. (2012), Sterman (2000), Parnell et al. (2008), and Pownall (2012).

The diagram shown in Figure 3 shows the general aspects common to all soft methodologies (Daellenbach et al. 2012). The major processes here are formulation of the problem, system action and modeling and implementation—similar to hard OR methodology. All processes within and between phases involve several iterations until system analysts/designers are satisfied. Also, it should be noted that there is considerable overlap between the first two phases. Problem formulation and modeling can hardly be completed satisfactorily at one shot because of many reasons (such as changes in environment and perceptions, insufficient experience or knowledge, etc.). The work team has to iterate between these two phases until an acceptable model is constructed.

As a final remark in this section, the readers are referred to the Cybernetic control structure shown in Figure 4. This structure is general enough to be applicable in any discipline, whether it is pure science, or engineering, or social sciences. This control structure is helpful to designers to see the role and the position of decision making in the system. In this basic control cycle, the receptor (or sensor, or detector) registers are various stimuli. After its conversion into information, it is sent to the controller unit. The comparator (or discriminator) compares this value with a desired standard, and the difference, being a corrective message, is implemented by the effectors (or activator). Through monitoring and response feedback to the receptor, self-regulation is achieved. The controller may take a more sophisticated role when it includes a goal-setter with its standard reference, and a decider (or selector). For instance, if a managerial control system is being designed, the

designer will find it easier to relate decision making processes to the rest activities in the management structure.

CONCLUSIONS

In this paper, complexity management and complexity decision making are viewed from the GST perspective. In particular, the issues involved in complexity decision making are assessed within Cybernetics, Managerial Cybernetics, and Soft Systems Thinking contexts. The importance of designing self-organizing and evolutionary systems via organizational learning and intelligent knowledge management approaches is emphasized. A framework was developed with the intension of guiding instructors teaching in complexity management and decision making areas. It is suggested that the students need to learn fundamentals of GST and Soft Systems Thinking before they move into complexity decision making. It was further argued that, through Systems Thinking and Soft System Methodologies, it is possible to develop a rich and structured description of a messy problematic situation and resolve a complex decision making problems effectively.

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