MODELING COMPLEXITY: HOLISM VERSES REDUCTIONISM AND THE POTENTIAL FOR DISTORTION AND ERRORS THAT MAY OCCUR DUE TO EITHER DIMINUTION OR ABSTRACTION OF A COMPLEX SYSTEM.

Anthony W. Dean, Ph.D., Old Dominion University

Abstract
Systems, Cybernetics, and Complexity all share an orientation towards the model of organization of phenomena in taking a "big picture" perspective. Using a holistic view the system is observed in its entirety to model 'complexes of information and meaning' such as patterns, configurations, processes, and types. Conversely from a reductionistic view, an attempt is made to decompose complex activities and localize the components within the complex system to provide a foundation for dynamical analysis. Both theoretical frameworks share a base in scientifically derived knowledge, an interest in understanding non-living (artificial/machine) and 'living systems', and a belief that to more properly understand phenomena, a larger, more inclusive view is necessary. This paper attempts to reconcile the apparent contradiction of not being able to predict (stochastically or otherwise) a complex situation, where the prediction is an underpinning of the research, by addressing the concepts of holism and reductionism, and the potential distortion and errors that may occur due to diminution or abstraction of a complex system.

Introduction. Systems, Cybernetics, and Complexity all share an orientation towards the model of organization of phenomena in taking a "big picture" perspective (Kuhn, 2002). From a holistic view the system is observed in its entirety to model 'complexes of information and meaning' such as patterns, configurations, processes, and types. From a reductionistic view, an attempt is made to decompose complex activities and localize the components within the complex system to provide a foundation for dynamical analysis (Bechtel, 2001). These diametrically opposed views have been characterized (Ragin, 1989; Verschuren, 2001) as the (holistic) case model as 'case-oriented', in contrast to a (reductionistic) 'variable-oriented' approach. Often in research we can also describe them, respectively, as qualitative and quantitative. Both theoretical frameworks share a base in scientifically derived knowledge, an interest in understanding non-living (artificial/machine) and 'living systems', and a belief that to more properly understand phenomena, a larger, more inclusive view is necessary. Van Gelder (in Bechtel, 2001), for example, identifies homuncularity, the idea that one can analyze systems into components, as allied with such notions as representation, computation, and sequential and cyclic operation, all of which he views as incompatible with and supplanted by a dynamical approach. Efforts to decompose and localize processes are often ridiculed [by holist] as reductionistic and conceived of as unable to explain the operation of complex systems. Recognizing that phenomena can be more properly understood as parts of systems also implies that the observer has the ability to delineate with some security the proper systems and/or components of systems implicated when investigating any specific phenomena (Kuhn, 2002).

Developing a Reductionistic Model. As engineers, scientist and researchers, decomposition of a complex system into its subsystems and elements for model development is an attempt to isolate variables that uniquely determine the state of the complex system under model. The number of elements that make up a system and the large number of interactions among those elements contribute to the existence of complexity. Given that complex systems have the common characteristic of structure (Biggiero, 2001; Flood and Carson, 1993), often the researcher will use that characteristic to develop a model of the system. As researchers, and definitely as pragmatists, we are "forced" to develop models that have predictive capability. The reductionist has to make the assumption that the holistic view of the system that he has chosen to decompose is accurate and that the variables that uniquely determine its state are known. In principle, the application of such a theory to real problems requires the simultaneous measurement of all these variables. This is rarely feasible in practice, where often we will not even know what the important variables are. All that we may be able to achieve is to make a sequence of repeated measurements of one or more observables. The relationship between such observations and the state of the system is often uncertain. It is therefore unclear how much information about the behavior of the system we can deduce from such measurements (Stark, 2000).

In the true metaphysical application of reductionism, as it is characterized in the philosophical literature, it may in fact be difficult to express the operation of a complex system once it is decomposed into its components, but from the ontological perspective of a systems engineer there is logic in the decomposition of a large complex system. Reduction of a system into its base parts allows the researcher to achieve to goals, one being quantification the other being able to establish researcher independence (Verschuren, 2001).

Quantification allows for the establishment of a metric means for measurement. This measurement allows for comparison of the results of the research, as well as replication and control of what the researcher has accomplished. Additionally, quantification allows for the counting of observation units having certain characteristics thus allowing for multi-variant data analysis. Finally the belief that quantitative research is more valid than qualitative research, due to its subjectivity, lends to the widespread use of quantitative research (Verschuren, 2001).

Verschuren (2001) puts forth that a reductionistic type of data gathering may help achieve researcher-independent results This would allow for systematic observation and quantitative content analysis, rather than for participant observation and open-ended qualitative content analysis. A final argument for reductionism is that the differentiation between research units and observation units may act as a kind of cross-validation.

As most hypotheses come into being inductively as an overall impression of the researcher, testing them in an inductive way ceteris paribus is weaker than doing this reductionistically. For instance, imagine a researcher formulates the hypothesis that of two groups the members within group 1 interact significantly more than those of group 2. Then looking at all dyads in each group, counting the number and duration of interactions per dyad within a certain period and summating over all dyads and periods, for most people will be more convincing as a test of the hypothesis, than an overall impression of a researcher who observes these groups as wholes. This confidence is based in large part on the fact that the researcher often has a number of ideas and implicit assumptions as to the object of research. By looking at its elementary parts (i.e., observation units) instead of at the object as a whole, a professional researcher will 'forget' these assumptions and ideas for the simple reason that these do not directly regard the individual parts (Verschuren, 2001).

Developing a Holistic Model. With the idea of a "complex" system in mind, it becomes important to clarify the notion of what constitutes a complex system. While various methodologies exist for the development of system-based initiatives, each methodology must adhere to a basic underlying group of principles to ensure that an effective model and an understanding of the system, in its current state, is achieved. The specific approaches may differ but the underlying 'logic' is a common thread running through each of the methodologies (Keating, 2000). The following four system tenets amalgamate the concept of complex system analysis.

- Simple vs. Complex Systems
  - Characteristics of a complex systems (Jackson in Keating et al, 2002)
    - Large number of variables or elements
    - Rich interactions among elements
    - Difficulty in identification of attributes and emergent properties
    - Loosely organized (structured) interaction among elements
      - Probabilistic, as opposed to deterministic, behavior in the system
      - System evolution and emergence over time
      - Purposeful pursuit of multiple goals by system entities or subsystems (pluralistic)
      - Possibility of behavioral influence or intervention in the system
      - Largely open to the transport of energy, information, or resources from/to across the system boundary to the environment
  - Characteristics of a simple system
    - Small number of variables or elements
    - Poor interactions between elements
    - Ease of identification of attributes
    - Deterministic behavior in the system
    - System does not evolve over time
    - System is not effected by behavioral influences
    - Largely closed to the transport of energy, information, or resources from/to across the system boundary to the environment
- Self-Organization. Self-organization holds that most of the structural and behavioral properties of a system emerge through interaction of the system elements (Clemson, 1984). Therefore, the actual design of a system can only be partially specified in advance of system operation. From the systems perspective, this explains why the most thoughtful and carefully designed systems have unintended consequences. In essence, system behavior and informal structure emerge only through system operation, regardless of the detailed design efforts conducted prior to system deployment.

  "Effective design of complex systems ensures that only the essential constraints are imposed on the operation of the system. In systems theory this concept is known as minimum critical specification (Cherns). Over-specification of system requirements is: (1) wasteful of scarce resources necessary to

monitor and control system performance, (2) reduces system autonomy which in turn restricts the agility and responsiveness of the system to compensate for environmental shifts, and (3) fails to permit subsystem elements to self-organize based on their contextual knowledge, understanding, and proximity to the operating environment. Therefore, self-organization suggests that system solutions should specify only the minimal requirements necessary to achieve system objectives." (Keating, 2000)

- System Darkness. This concept suggests that the complex system when viewed from any vantage point will not clearly present itself in its entirety. The complex system and any representation of the complex system can only be described by what is known, observed or suspected. Unknown, unobserved, unrepresentative, and emergent characteristics will be present and not known to the systems architect.
- Complementarity. The principle of complementarity suggests that "Any two different perspectives (or models) about a system will reveal truths about that system that are neither entirely independent nor entirely compatible" (Clemson, 1984). Each system perspective is correct from a particular vantage point of the system. In addition, each system perspective may also be considered, to some degree, incorrect from an alternate system vantage point. The important argument is that there are multiple system vantage points, each adding to a more holistic impression of the system. Shifts in vantage points, environmental conditions, or knowledge will influence perspectives of a system. It is naive to consider there is only one system perspective that is "correct". Therefore, it is a mistake to conduct inquiry as to which system perspective is 'right'. Assumption of a 'right' system encourages advocacy and competition instead of dialog and collaboration. (Keating, 2000)

Additionally, a system model must also address the needs of the individual(s) who express interest or concern for the performance of the system to meet a desired outcome or functionality of the system under model. To accomplish this task, a set of criteria needs to be established to determine whether the system architect has developed a level of competency in understanding the system under model, and has determined an effective method of addressing the concerns of the desired outcomes of the system. The use of the developed criteria can then be used to evaluate the model (design, approach, accomplishment, effectiveness, strengths, weaknesses, etc.).

Developing a holistic model is a matter of "fit" between the contextually rich interrelationships of the system, the problem context and the methodology selected to evaluate the system. A big mistake that proponents of a holistic approach are prone to make is to follow a stepwise progression through a particular methodology because they are comfortable with it. The system and problem context must "choose" the methodology, not the other way around.

- Methodology selection. What is the methodology(ies) that best fit the situation? How was that determined and by who?
- Application of the methodology. Was the methodology(ies) selected properly applied in the analysis of the system?
- Development of a systems model. The model should be an abstract of the system under model. To what level of detail was the model developed?
- Goodness of Fit. By "goodness of fit" we try to identify the rich contextual relationships between the methodology used by the systems architect to model the system and the problems identified by the problem context. This attempt should be satisfying. Does the methodology used fit the problem and the system as developed in the problem context and the system model?
- Representation effectiveness. Does the model effectively and efficiently depict the system and the complex interrelationships of the system (interaction of system with its environment, interaction of the subsystems)? Does the model identify gaps in our knowledge of the system?
- Limitations and assumptions for system representation. What are the assumptions and limitations of the model? What does/does not the model express?

The individual's ontological view of the world tends to bias the perspective from which they would observe the system. The level from which the observer views the system (Checkland, 1999) lays the foundation from which the researcher, as an observer, bases his assumptions in a holistic model. The researcher's viewpoint is predisposed due to the worldview he posses. While basic truths may exist in the system as a whole, the viewpoint of the observer is based on knowledge that the observer has gained throughout his entire existence. He has developed a knowledge basis from which he has tried to adapt to the given situation, which has resulted in the formation of his viewpoint of the situation. That is to say that the system exists on many levels, but the view from which it is to be observed, and the model developed, is dependent solely on the observer.

This implies that the oversimplification of a model results from a lack of knowledge on the part of the observer. From a systems analysis viewpoint, simplification is not necessarily a bad thing.

> "It clearly makes eminent sense to move onwards from the simplest (least complex) available solution to introduce further complexities when and as – but only when and as – they are forced upon us. Simpler (more systematic) answers are easily more codified, taught, learned, used, investigated, and so on. The regulative principles of convenience and economy in learning and inquiry suffice to provide a rational basis for systematicity- preference. Our preference for simplicity, uniformity, and systematicity in general, is now not a matter of a substantive theory regarding the nature of the world, but one of a search strategy – of cognitive methodology. In sum we opt for simplicity (and systematicity in general) in inquiry not because it is truth-indicative, but because teleologically more effective in conducing to the efficient realization of the goals of inquiry. We look for the dropped coin in the lightest spots nearby, not because this is – in the circumstances – the most probable location but because it represents the most sensible strategy of search: if it is not there, then we just cannot find it at all" (Rescher, 1998)

In general, the simple model is a manifestation of what the researcher presumes to know, his base approximation of the system. While this concept at first seems a little clouded, an interpretation of this concept is as follows: From the perspective that the system is viewed (ontologically), a model is developed. There must be a base level of knowledge about the system to effectively engage in a systems-based initiative, which results in the development of the initial framework of the interrelations of the system's conceptual units (Checkland, 1999). Through trial and error, the researcher gradually adjusts the model (problem solving expertise), with each iteration, in an attempt to achieve a bridging of the gap between the ideal outcomes of the system and the actual outcomes of the system (gap – the problem domain). With each iteration, knowledge is gained (epistemological part) as to the assumptions the researcher had to make as he adjusted the model. The iterations themselves revealed to the researcher as to whether his initial assumptions of the unit's interrelations were true or false. Progressing through the iterative process, the researcher is learning about the system and gaining knowledge that did not previously exist. As the researcher gains knowledge during this process, it will become evident to the researcher that the model must then be reoriented to reflect the new knowledge. The result is a more mature level of systems knowledge compared to the base knowledge the researcher began with. This mature knowledge will lead to a greater understanding of the actual system under model and more effective insight/resolution to the disparity of the ideal and actual system outcomes (gap closure).

Assuming that the model of the system is a dynamic model, based on an iterative modeling process, and given the ontological and epistemological view of a researcher attempting to model a system for model, the following four points (as derived from the literature) are proposed as a counter argument to the effects of oversimplification of a model.

Point 1. *There is no perfect "true" model of any system. For a given system several models may exist (from an ontologically materialistic view) that may be adequate for solving the problem situation faced by the researcher.*

Any systems model developed is based solely on the viewpoint of the observer (Checkland, 1999). The observer's base knowledge of the system establishes the functional utility for the framework of the system component relations in achieving systems goals (outcomes). As in the 'black box' theory, numerous independent observers who are at consensus with the inputs view the system and outputs of the system, yet are in disagreement about the transformation processes that occur within the system. As the researcher gains knowledge of the diverse communications and actions of the units that comprise the system, an approximation of the true nature of the system is developed, but is only an approximation. With multiple observers, many diverse approximations will be developed; most will be quite different based only the observers ontological view.

Point 2. *Acceptance of the knowledge gained by the researcher will tend to be rejected if it is inconsistent with the bulk of knowledge possessed (base knowledge) prior to system model.*

If an individual(s) or group(s) evaluates a system model modified by a researcher after multiple iterations, without the individual(s) or group(s) having the maturity in knowledge the researcher has gained through the iterative process, a dysfunctional dynamic will exist between the researcher and that individual/group (Gibson, 1991). The individual/group lacks the ability to effectively evaluate the model because it does not comprehend the system at the same knowledge level the researcher is presenting in the "iterative" based model. In order for the model to become acceptable, the individual/group must be brought up to the knowledge level of the researcher through other means, else the knowledge gained by the researcher will be lost on the individual/group expressing interest in the system of model.

Point 3. *A systems based methodology is chosen to fit the ontological and epistemological view of the researchers "best fit" model. How the researcher views the system is fundamental in determining his approach to "problem solving".*

The model is only a conceptual representation of the researcher's approximation of the system. Does the model effectively and efficiently depict the system and the complex interrelationships of the system (interaction of system with its environment, interaction of the subsystems)? Does the model identify gaps in our knowledge of the system? While these questions come to mind when thinking about the model, the methodology must fit the problem context (Guarino, 1995). In relation to the model, problem context is the perception of the researcher of the gap between the ideal outcomes of the system and the actual outcomes of the system. Again, the context (like the model developed) is a function of the ontological view and base knowledge of the researcher.

Point 4. *Models are not static representations of the system being studied. Models will change as knowledge is gained.*

The model is an entity and representation of the system under model. It is not the system itself. The framework (base knowledge) and conceptual units of the system created by the researcher are an attempt to examine and explain system behavior (Checkland, 1999). As the iterations of the model progress, further knowledge is gained and the initial framework and conceptual units must be altered to reflect this (Gibson, 1991).

It is most important to note that the results of a systems model are highly subjective and duly apt to interpretation to those individuals who read them. A system model is intended for the use of the individual(s) (or stakeholders) who perceive a problem with the actual outcomes of the system as it was currently operating based on their individual perspective. The individual is naturally biased in his/her perspective based on his/her own ontological stance. Even in the reading of the model, the interpretations and use of the presented work is highly subjective and innately dependent on the ontological and epistemological views of the reader (Cocchiarella, 1996). As stated previously, acceptance will be based on knowledge individuals already posses.

Morgan introduced five approaches to lessen a similar paradox in the determination of research dilemmas faced in management science (in Gill and Johnson, 1991). While the underlying concepts are true in systems science, the concepts have modified here to more appropriately correspond with systems science. The researcher should ask the following questions about his analysis.

1. What was the intended use of the body of work produced by the researcher? Is the work relevant to the problem?
2. What were the objectives of the stakeholders? Were these objectives addressed in the model?
3. What was the researcher trying to gain from the model of the system? Did the model produce a work that is usable by others to obtain their goals?
4. Were the limitations, assumptions, and judgments made by the researcher consistent with the perspectives of the stakeholders?
5. Did the researcher "look outside the box" of a particular methodology to determine the best approach to the situation?

By attempting to keep those questions mindful, the researcher will address the concerns of the interpretation and use of his work when applied to the system studied.

Reductionism vs. Holism. While reductionism on the surface, appears to be a most valid means to approach to isolate the variables necessary to understand a complex system, there are some limitations to the reductionistic approach in building a model of a complex system. There is a familiar idea that the whole is more than the sum of its parts. Petrinovich (1976) points to the major difficulty with reductionism stemming from two sources:

(1) It distorts the structure of natural events, and
(2) It embodies a misleading conception of the meaning of individual differences.

The first point refers to the fact that to use techniques such as analysis of variance one must select a range of stimulus values in some arbitrary fashion, must choose a dependent variable to measure that is arbitrary, and often limiting operational translation of the conceptual variables in which the in which the experimenter is interested and must abstract the entire experimental operation out of a complex of variables in which the behavior is embedded.

By separating the variables controlling the behavior from the fabric from which they are embedded, the pattern of correlations between variables as they exist in nature is destroyed. Context dependencies, interconnectedness, and functionality are lost. '*Because a cause was taken to be sufficient for its* *effect, nothing was required to explain the effect other than the cause. Consequently, the quest for causes was environment free. It employed what is now called 'closed-system' thinking'* (Ackhoff in Kuhn, 2001). In order to establish the viability of research surrounding the development of the deconstruct subsystem model requires the acceptance of the principle of determinism. This principle implies that general laws exist which allows for the complete predictability of behavior if measurement is precise and if all relevant variables could be controlled. It also implies that the system had been deconstructed such that the subsystem under observation is no longer complex and completely understood.

Verschuren (2001) clarifies the second difficulty with reductionism, "In general not the sum of individual parts of a system makes up an equilibrium, but the integrated whole of a system." His statement alludes to the concept that without the holistic view, there is not a way to determine how perturbations to the deconstruct subsystem model will effect the behavior of the complex system. This suggest that the knowledge gained by isolating the subsystem for model may not have a significant use in understanding the complex system's response (macro) to the stimulus introduced at the subsystem level (micro).

Conclusions. In order to reconcile the problem of not being fully able to predict the behavior of a complex system through the development of complete models with full predictive capability though either holistic or reductionistic reasoning, the following assertions are put forth:

- While important to establish a base knowledge level when modeling a complex system, system models do not represent the system but serve as an approximation of the system and current knowledge base of the researcher.
- Models of complex systems require an iterative development process to allow for variability inherent in complex systems and modifications due to gained knowledge of the researcher.
- Statistical and other quantification methods, used in conjunction with reductionism to evaluate the behavior of the subsystem, may not yield the same results when applied at the system level.
- Reductionism should be used in conjunction with holism to identify those variables in the system, which control "meaningful proportions" of the total variance in behavior of the complex system.
- Predictions made from the use of complex models will be probabilistic at best.

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About the Author

Anthony W. Dean is Assistant Professor of Engineering Technology at Old Dominion University and a 2004 NASA Faculty Fellow. He received a Ph.D. in Engineering Management and a B.S. in Engineering Technology from ODU. Additionally, Dr. Dean also received an MBA from the College of William and Mary. Prior to his appointment, Dr. Dean was Director of Operations and Business Development for Clark-Smith Associates, P.C., and served in the U.S. Navy aboard the USS South Carolina and the USS Enterprise.