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# Complex System Contextual Framework (CSCF): A Grounded-Theory Construction for the Articulation of System Context in Addressing Complex Systems Problems

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# COMPLEX SYSTEM CONTEXTUAL FRAMEWORK (CSCF)

# A GROUNDED-THEORY CONSTRUCTION FOR THE ARTICULATION OF SYSTEM CONTEXT IN ADDRESSING COMPLEX SYSTEMS PROBLEMS

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## ABSTRACT

COMPLEX SYSTEM CONTEXTUAL FRAMEWORK (CSCF)
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The complexity of problems facing society continues to grow, and decision-makers and problem-solvers are finding many of today's emerging problems to be beyond their capability to adequately address. There is agreement in the literature that problems of this nature are complex system problems, inextricably linked to some highly complex system of systems. Establishing a clear understanding of the specific complex system context is fundamental to the process of understanding and analyzing complex systems and complex system problems across all of the different systems-based disciplines. While complex system context is widely referred to in systems literature, there is no clear characterization of exactly what system context is, making this foundational system concept ambiguous. This research addressed this gap in the systems body of knowledge by providing the needed detail and clarity to the concept of complex system context. A rigorous research methodology, employing the grounded theory method, was used to analyze data collected through a series of semi-structured interviews conducted with individuals reflecting a wide range of systems education and practical experience. Two research questions were identified as integral to increasing the understanding of context within complex systems.

- What are the constituent elements of complex system context, and what attributes and dimensions characterize these elements?
- What systems-based framework can be developed for constructing and articulating complex system context?

Using the grounded theory method, a theory of system context was constructed, adding to the systems body of knowledge and substantiating a comprehensive and unambiguous theoretical construct for system context within complex systems. Then, based on this theory, a conceptual model to articulate and capture system-specific complex system context was developed – the Complex System Contextual Framework (CSCF). The CSCF shows significant promise for contribution to systems practitioners by supporting the future development of tools to help practitioners capture system context as a part of complex system problem formulation. The research also made a contribution in the area of research methodologies by furthering the use of the grounded theory method in the engineering management and systems engineering domain, an area where its application has been very limited.

To my most precious Dee -
You are my loving wife, my best friend, my soulmate... my one and only.
You are the one person in my life who has always been there for me.
Thank you for your unconditional love and for being the one I always knew I could count on... NO MATTER WHAT.

**ACKNOWLEDGEMENTS**

I would like to thank my dissertation advisor, Dr. Chuck Keating, for his insight, counsel, and guidance through my research endeavor from concept to completion, and the members of my committee for their review, critical evaluation, and advice. In particular, I also extend my sincere gratitude to my peer reviewers, Tom Meyers and Dennis Popiela, whose willingness to give up many hours of their time to review and critique my research played a key role in ensuring a quality product in the end.

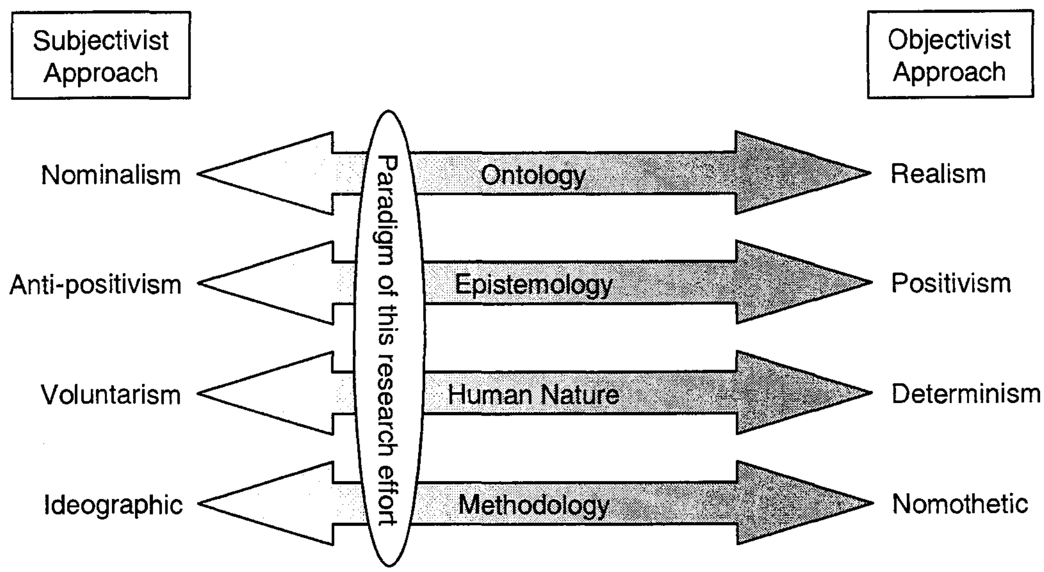
To my sons, Eli and Luke: Thank you for your understanding and encouragement over many years of my academic undertakings. Even though it took time away from you, you always let me know that you supported me in what I was doing. I am exceptionally proud of you both.

Most importantly, I want to thank my lovely wife, Dee. On top of your job and all of the other things you had always done, you took upon yourself the roles of both mother and father and the full responsibility of running our home so I could focus on my work for this degree (and two previous ones). You were beside me through all of these years of academic pursuit – helping with research, being my most critical proofreader and editor, repeatedly showing me a better way, and always trying to keep me organized and on track. It is no exaggeration to say that I would never have completed this program, nor would I be where I am today, without you.

# PREFACE

This research was conducted in order to contribute to the ongoing efforts of many in the systems engineering field to expand upon the concepts and methodologies that have been applied for years in what is sometimes referred to as 'traditional' systems engineering and to move them into the domain of complex systems and systems of systems. Specifically this research was undertaken to contribute to the further advancement and development of a methodology for Systems of Systems Engineering. The primary motivation for choosing this area for research was twofold. First, after 22 years in the military and 5 years in the defense industry, the exigency of the requirement for better methods of addressing complex problems was unmistakable. Systems theory and concepts related to complex systems seemed to provide a reasonable approach to dealing with this need. Secondly, during the initial coursework of the doctoral program, two concepts surfaced regarding complex system context – 1) understanding context is integral to the process and had to be addressed before beginning to attempt further systems engineering efforts especially when dealing with complex systems; and 2) that the body of knowledge represented by systems literature had not adequately addressed the concept of complex system context and as such, the idea of context was ambiguous and ill-defined.

This research was undertaken from a specific paradigm or philosophical perspective that had a significant influence on the research design and the selection of the grounded theory method as the foundation for the research methodology. Chapter III of this dissertation introduces a model or schema of the philosophical domain upon which the philosophical basis of any given research initiative can be depicted by identifying the research paradigm's position along four dimensions: ontology, epistemology, human nature and methodology. The graphic below illustrates that the




(Adapted from Burrell and Morgan, 1979)

paradigm adopted in this research effort definitely tended toward the subjectivist or interpretivist end of the spectrum. This perspective views 'reality' more as being dependent upon the interpretation of the observer than being objective, and considers knowledge not so much as acquiring some concrete truth but rather as being experientially-based and viewed from the perspective of individuals involved in activity. This is presented here because appreciating the viewpoint taken in this research is key to understanding the manner in which the research was conducted and the conclusions drawn from it.

This dissertation is presented in a traditional form for research of this type; however, there is one somewhat unique element. Chapter III, Research Perspective, is unique because it is an entire chapter dedicated to the discussion of the research perspective. It was included because, as stated above, understanding the worldview taken in the research was foundational to the entire research effort. Chapter III includes discussions on philosophical paradigms, a systems philosophy, implications of systems philosophy misalignment, and introduced the topic of theory discovery and the grounded theory method. It concludes by addressing several grounded theory research design concerns. The topics of the remaining chapters include: Introduction (Chapter I), Literature Review (Chapter II), Research Methodology (Chapter IV), Research Results and Theoretical Construction (Chapter V), and Conclusions and Recommendations (Chapter VI).

The conclusions drawn from this research provide an excellent point of departure for a wide range of future research in the area of systems engineering, specifically focusing on the issue of system context in complex systems or systems of systems. Also, the Complex System Contextual Framework (CSCF) developed as part of the research gives systems researchers and practitioners a means of capturing, articulating and assessing the unique context of a given complex system. These contributions meet the initial intent of the research.

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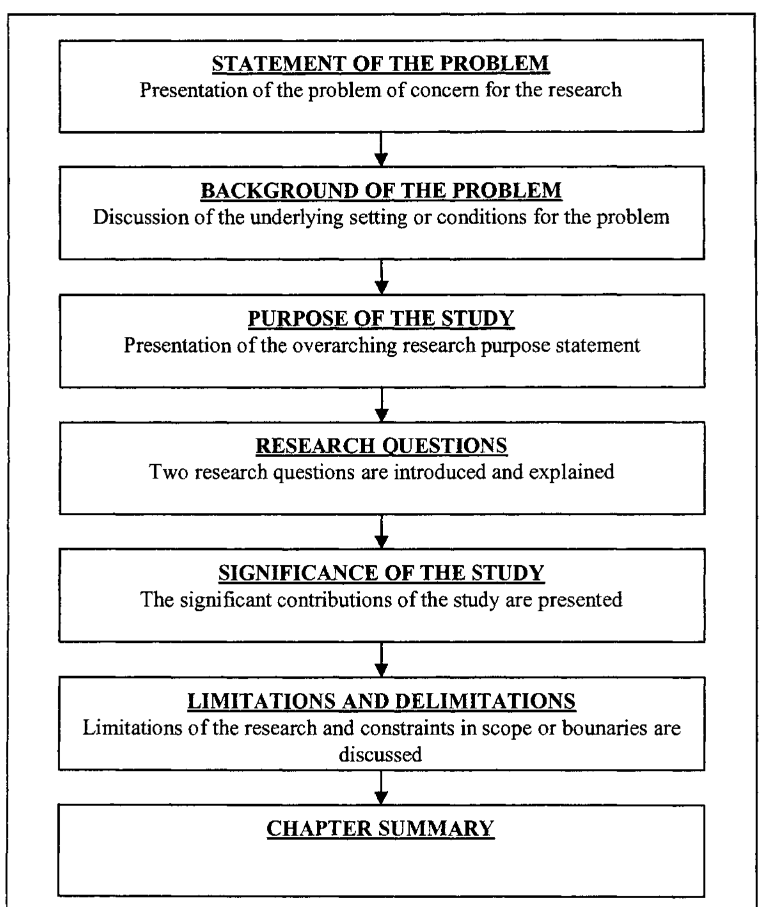
# CHAPTER I

# INTRODUCTION

The purpose of this chapter is to lay the foundation for research that addresses a significant deficiency in the body of knowledge surrounding complex systems and systems-based approaches to complex system problems. This was done through the formation of a theoretical construct for complex system context, which supported and underpinned the further development of a Complex System Contextual Framework. Exhibit 1 below provides a layout of Chapter I.

**Exhibit 1. Chapter I Layout Diagram**

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Style conforms to the *Engineering Management Journal Model.*

## STATEMENT OF THE PROBLEM

A common thread that runs through the literature on systems-based approaches to complex systems problems is the importance of problem formulation, and more specifically, the critical nature of understanding and accounting for system context during the formulation phase of a systems engineering or other systems-based analysis effort. Further, it is noted that as systems problems increase in complexity, context becomes even more critical to analysis of the system and the associated complex system problems (Bergvall-Kareborn, 2002a, 2002b; Chacko, 1976; Checkland, 1985; Gibson, 1991; Keating, 2000; Keating et al, 2001, 2003b, 2003c; Keating and Sousa-Poza, 2003; Murthy, 2000; Hitchins, 2003; Quade and Miser, 1985). However, while complex system context is discussed in the literature, there is a lack of clear definition or characterization of what is meant by the term, resulting in a significant shortcoming in the body of knowledge related to systems-based approaches to addressing complex problems.

The following sections of this chapter introduce the research by offering the study's background and purpose, the research questions, a discussion of significance of the research, and limitations and delimitations of the study.

## BACKGROUND OF THE PROBLEM

In a discussion of system context as part of the analysis of highly complex systems of systems (metasystems), Keating and Sousa-Poza (2003) refer to the process of framing system context as "the most critical phase... since errors in this phase will be amplified at later phases and throughout the cycling of the SoSE [systems of systems engineering] effort" (Keating and Sousa-Poza, 2003, p. 10). According to Gibson (1991), establishing and maintaining 'contextual integrity' throughout the analysis of complex systems is crucial to the success of the project. These and similar thoughts in the literature point to the significance of the need to understand system context in any endeavor involving the analysis, engineering, design, redesign, or transformation of complex systems. Comments such as this form the underlying foundation of the research.

## PURPOSE OF THE STUDY

The purpose of this research is to use the grounded theory method to develop a framework for context within complex systems.

The grounded theory method was first articulated by Glaser and Strauss (1967) who maintained that their approach supported the discovery of theory from data, providing researchers a methodology for developing theoretical constructs from a broad range of data. The grounded theory method is described in detail in Chapters III and IV.

The concept of complex systems is elaborated upon extensively in Chapter II; however, in order to fully understand the purpose of the study as spelled out in this section, it is necessary to capture how this term is being used here. For this purpose, complex systems were considered as those systems for which the amount of information required to describe the system and resolve any uncertainty about it is high (Klir, 1985). Such systems typically exhibit one or more of the following attributes: "1) significant interactions; 2) high number (of parts, degrees of freedom or interactions); 3) nonlinearity; 4) broken symmetry; and 5) nonholonomic constraints" (Yates, 1978, R201).

This research addressed the gap in the systems body of knowledge introduced above, the lack of clarity of meaning of complex system context, by presenting a framework for establishing and articulating complex system context within the domain of and in support of systems-based analysis of complex systems problems. As used in this purpose statement, the term framework refers to a model that can be applied in carrying out some specific function or task. This framework is referred to as the Complex System Contextual Framework.

Meeting this research purpose required further granularity regarding what the research intended to achieve and how it was going to be done. This was articulated by developing two specific research questions, as presented in the next section.

## RESEARCH QUESTIONS

This research built upon the existing foundation of systems theory and emerging theoretical constructs surrounding the study of complex systems. The research was specifically focused to answer the following two research questions:

**1. What are the constituent elements of complex system context, and what attributes and dimensions characterize these elements?**

**2. What systems-based framework can be developed for constructing and articulating complex system context?**

As used above, the term constituent element refers to the basic or fundamental elements of systems context. These are the basic building blocks that must be identified and understood in order to capture complex system context. The first question is focused on identifying these elements or building blocks of system context. The goal of the research was to ascertain what all must be analyzed and understood in order to build the contextual foundation for a complex system problem. Utilizing a grounded theory methodology, the investigation was then directed toward discovering the characteristics or attributes that identify and distinguish each of the elements of context developed above. Additionally for each attribute, a set of dimensions was established to describe each of the given attributes or characteristics. In a simplified example, if one of the elements of context were identified to be color, then color could be characterized by attributes such as shade, hue, intensity, etc. In order to identify a specific color, each of these attributes must be further characterized by a set of dimensions: e.g., hue can be characterized by a dimension called darkness, which could be either dark or light; intensity could be characterized by a dimension called degree, which could be either low or high.

In the second research question, a framework is a conceptual model or paradigm that can be applied to carry out some specific function or task. This framework was not intended to be a detailed step-by-step approach, but rather a model that can serve as an outline or shell for the articulation of complex system context in complex systems. The strength of the framework is derived from its being grounded in the theoretical constructs derived from the research on complex system context.

As a result of addressing these two research questions, the research made a substantial contribution to the systems body of knowledge, furthering systems science and systems-based approaches to problem-solving. The following section discusses specific contributions of this research to the systems discipline.

## SIGNIFICANCE OF THE STUDY

As further elaborated upon in Chapter II, literature from a variety of disciplines establishes that problem definition or problem formulation forms the foundation of any problem-solving endeavor. The idea of clearly establishing the problem is of particular concern in the analysis of complex systems, and within this domain, system context is a major part of the formulation effort. This research made the following significant contributions to systems science and research methodologies:

- It added to the existing body of knowledge in systems theory and systems-based methods by presenting and substantiating a comprehensive and unambiguous theoretical construct for system context within complex systems.
- It contributed to systems literature by providing a basis for the expansion of the domain of systems-based disciplines. Through the development of a framework for the construction and articulation of complex systems context as part of the analysis of complex system problems, this research helped close a gap in the understanding of complex system context.
- As a foundation for development of methodologies in systems engineering and other systems-based approaches, the research made a significant contribution to systems practitioners who as part of their discipline take on the challenge of addressing the many complex systems problems facing society. This research may also support future development of tools to help practitioners in all

systems-based approaches with the task of dealing with system context as a part of complex system problem formulation.

- Lastly, this research made a contribution in the area of research methodologies in engineering management and systems engineering. Since its inception, the use of grounded theory method has expanded outside of its original domain of sociology, being applied in psychology, information science, education, health care, and management/organizational studies (Locke, 2001; Urquhart, 2002; Bryant, 2002a). According to Denzin (1994, p. 508), grounded theory "...is the most widely used qualitative interpretive framework in the social sciences today." However, its use within the realm of engineering management, systems engineering or other systems domains was found to be limited to a small number of studies. The further development and application of the grounded theory method within this domain greatly enhanced the ability to conduct the inductive research needed in this area for dealing with issues germane to engineering management and systems engineering, such as complexity, decision-making, situated (in situ) processes and relationships, change, individual and group behavior, and other issues of substance to systems-based approaches (Locke, 2001; Orlikowski, 1991).

This section addressed the contributions of significance made by this research to the systems discipline and in the expansion of grounded theory methodology into the systems domain. The following section presents the limitations and delimitations of the research.

## LIMITATIONS AND DELIMITATIONS

This section presents the limitations that must be addressed within the research and the delimitations that bound the scope of the research project.

### Limitations

There are four primary limitations identified related to this research. In this section, these limitations will be developed and associated research design implications will be discussed. The research perspective presented in Chapter III includes a detailed discussion of how these limitations were addressed and how the implications were mitigated in designing and conducting the research.

Validity and applicability of the grounded theory method – As presented in further detail later in Chapter III, there are those who significantly and substantively challenge the validity of the grounded theory method (Dey, 1999; Charmaz, 2002; Wilson and Hutchinson, 1996; Bryant, 2002a; Urquhart, 2002). Furthermore, as elaborated in the section on significance, the grounded theory method as a research approach has not been widely applied in research within the domain of the systems-based disciplines. These two issues of validity and applicability required the researcher to meticulously document key elements of the research approach such as data collection decisions, participant selection, coding choices, and construct development decisions, to ensure the maximum research transparency possible.

Generalizability – A major desired outcome of this research was for the concepts and framework developed for complex system context to be generalizable to the maximum extent possible. However, the qualitative nature of the research design and the grounded theory research methodology presented challenges to generalizability. As stated by Douglas (2003), generalizability is the goal, but there are limitations:

> "The explanatory power of grounded theory is to develop predictive ability – to explain what may happen to, for instance, a business or organisational sub-unit or a manager in a related context…the wider the theoretical sampling frame develops, the more embedded the theory becomes; and general theory generation becomes achievable… Transferability to other research areas depends on the degree of similarity between the original situation and the situation to which it is transferred" (Douglas, 2003, p. 51).

One of the potential origins of objections to generalizability or transferability is the use of purposive sampling and particularly the limited sample size. However, it has been established that when compared to most quantitative applications qualitative approaches such as the grounded theory method "typically produce a wealth of detailed data about a much smaller number of people and cases. Qualitative data provide depth and detail through direct quotation and careful description of… situations, events, people, interactions, and observed behaviors" (Patton, 1987 p. 9-10). This level of richness and detail is important to the development of the construct of complex system context. However, the impact of this sampling approach was lessened through what is referred to as maximum variation sampling, which is aimed at "capturing and describing the central themes or principal outcomes that cut across a great deal of participant or program variation" (Patton, 1987 p. 53). To create maximum variation within a small sample, the researcher selects several diverse characteristics for constructing the sample and then ensures that the variation of those key characteristics is represented in the sampling. For this research, this meant that the interviewing process, for example, had to include individuals with different experiences and backgrounds, which makes it "possible to describe more thoroughly the variation in the group and to understand variations in experiences, while also investigating core elements and shared outcomes" (Patton, 1987 p. 53). For this research, what must be understood is the degree to which the Complex System Contextual Framework was expected to be projected or generalized beyond the bounds of the data from which it has been constructed. Specific approaches and methods incorporated within the research to mitigate against this limitation on generalizability are presented in Chapters III and IV.

Sampling Strategy – Another limitation was the size and selection of the primary data source, which consisted of twelve interviews, a relatively small sample. While attaining credibility when using small, purposeful samples can be a challenge, according to Patton (1987), it can be achieved by anticipating the arguments that may be used to contest or object to the data, as well as those that will lend credibility to it. While there are no specific guidelines for determining the sample size when using grounded theory methods or other types of purposive sampling, the sample should strike a balance between being small enough to allow sufficient detail and depth of the data and being large enough to ensure credibility within the intended purpose and scope of the research (Patton, 1987). The "decisions about what one wants to be able to say with the data, for what purpose, and with what degree of credibility" (Patton, 1987 p. 59) have to be made in the design phase of the research. Once the research has begun, sampling decisions (e.g., selection of documentary data, selection of interview participants) must be transparent and explicit. It is likewise essential "to make explicit the reasons why any particular sampling strategy may lead to distortions in the data – that is to anticipate criticisms that will be made of a particular sampling strategy"

(Patton, 1987, P. 58). The sampling approach adopted in the research is discussed further in Chapters III and IV.

Perceptions of rigor of grounded theory research – A final limitation is the question of research rigor. One of the objections to the grounded theory method is that there are many examples where the technique was applied superficially, resulting in a severe lack of research rigor (Bryant, 2002a, 2002b). One additional element that can be included in the research design to increase the level of research rigor is triangulation, which can include "the use of a variety of data sources in a study, for example, interviewing people in different status positions or with different points of view... [or] the use of multiple methods to study a single problem or program, such as interviews, observation, questionnaires, and documents" (Patton, 1987 p. 60). Grounded theory methods advocate the use of multiple data sources and methods of data collection, such as "data from semi-structured interviews, from field-observations and from archival sources" (Locke, 2001, p. 45). In this research, the use of interview data and documentary data provided a source of triangulation.

**Delimitations**

This section discusses three delimitations of the research. Delimitations are those ways in which the effort was constrained or narrowed to limit the overall scope of this specific research.

The research did not look at end-to-end systems engineering or systems analysis processes, but rather focused a small portion of any systems-based analytical or engineering approach, that of problem formulation. However, as discussed in Chapter

II, it is at this point in the application of systems-based approaches where system context is assessed, analyzed, and captured. As such, the focus of this research was not on how to develop solutions or recommendations for improvement or transformation of a given system under study; nor did it consider the detailed system analysis that must be carried out in order to develop those proposals.

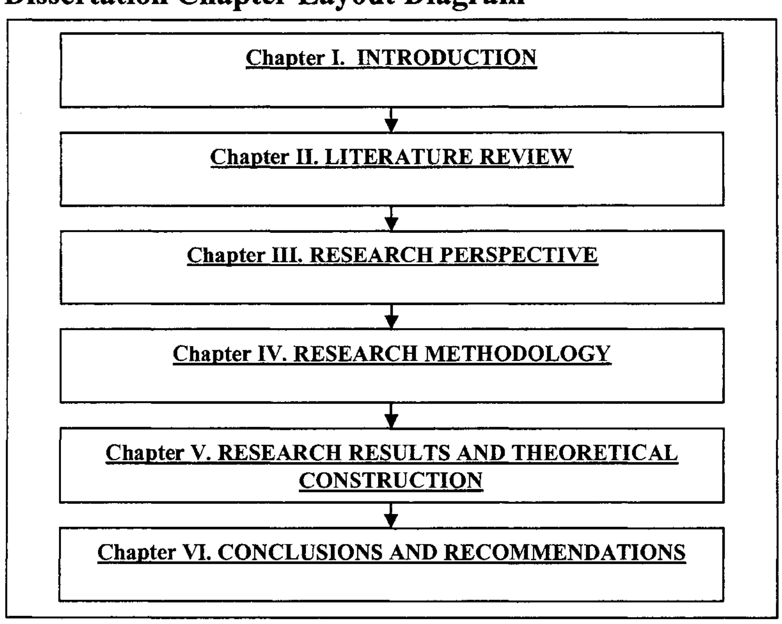
As stated earlier, the framework that resulted from the research is a conceptual model of complex system context of any complex system. It is important to emphasize that it is not a representation of and does not have direct applicability to the local context of any of the specific complex systems or complex system problems addressed within the interviews or any other data source. Rather, the framework provides a high-level conceptual structure, which can be applied to any complex system and provides an intuitive and unambiguous depiction of system context.

Lastly, as discussed in Chapter IV, this research did not take into consideration the gender, age, ethnicity or other aspects of the participants in the interview process. These characteristics were not considered germane to the research questions and as such were not the focus of the research.

**CHAPTER SUMMARY**

This chapter, Chapter I, provided an introduction to the research, the problem being considered, and the approach being taken to investigate it. The research outlined in this introduction is reported in the following chapters. Chapter II establishes the research setting for development of the CSCF by presenting a review and critique of pertinent literature and a discussion of key concepts and perspectives related to complex system context. The overarching research perspective is described in Chapter III, including discussions of the theoretical underpinnings of the grounded theory method, and of the development of a systems philosophy as a key foundation to the study. Chapter IV presents the research methodology by laying out the research design and research phases, and then explaining the approach taken for data collection and application of grounded theory analysis methods. An in-depth discussion of the research results, development of the theoretical construct for complex system context, and presentation of the CSCF are included in Chapter V. Then, finally, Chapter VI presents conclusions drawn from the research, recommendations for application of the research results, and opportunities for further research. Exhibit 2 is an illustration of the flow of information presented in this dissertation.

**Exhibit 2. Dissertation Chapter Layout Diagram**

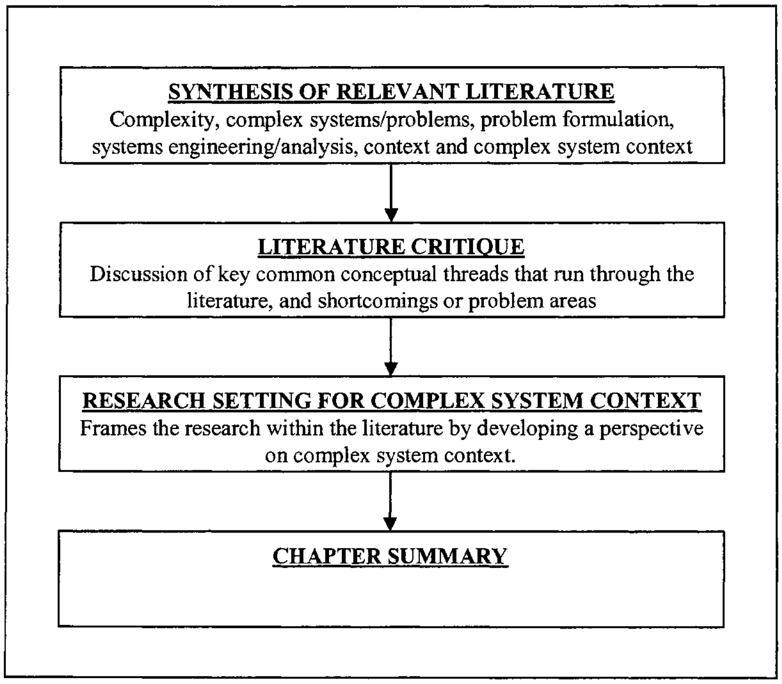


# CHAPTER II

# LITERATURE REVIEW

As stated in Chapter I, systems literature is replete with references to the importance of proper system or problem definition as part of any systems-based analytical approach, and the crucial role of establishing the context of the system. This chapter presents a review of literature pertinent to the concept of complex system context, and therefore germane to this research, providing a synthesis of ideas across a variety of research areas and perspectives, and a then critique of the literature. This is followed by development of a setting for the research, which frames the research within the literature and explains how it addresses shortfalls or gaps in the body of knowledge. Exhibit 3 illustrates the organization and flow of the literature review.

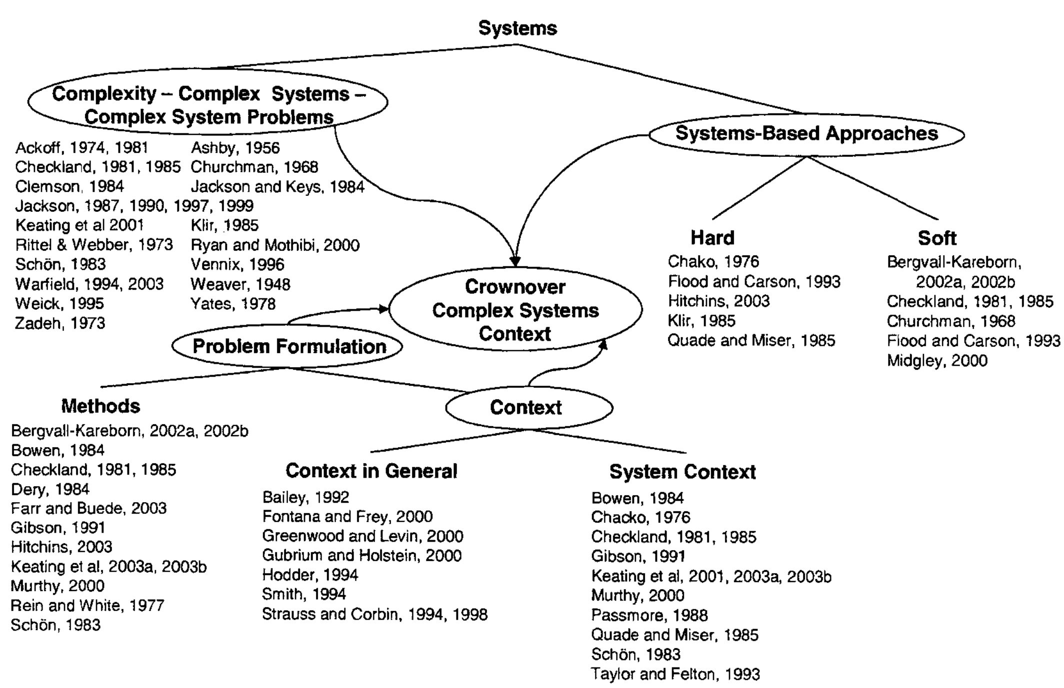
**Exhibit 3. Chapter II Layout Diagram**



## SYNTHESIS OF RELEVANT LITERATURE

This section presents a synthesis of literature related to the research, with the intent being to integrate and connect these various threads to build upon the idea of complex system context. The focus of the literature review is on the body of conceptual and theoretical literature available in the area of complex systems that specifically touches on those aspects related to context. In conducting the literature search, no current, ongoing research could be found that was investigating complex system context. In order to adequately establish the concept of complex system context, literature covering the topics of complexity, complex systems, complex system problems, problem formulation as part of systems engineering and systems analysis, context, and complex system context are included in this discussion. Exhibit 4 below illustrates the research threads pursued during the review of literature for the research.

### Exhibit 4. Threads of Literature Review



**Complexity and Complex Systems**

The notion of complexity is generally associated with those things that are difficult to understand. Basic discussions of the concept often look at the number of elements and the quantity of relationships between and among those elements to explain complexity. However, while things with very large numbers of elements and relationships are certainly complicated, they are not necessarily complex. The discussion of complexity must include a distinction between objective external reality and abstractions or constructed perceptions of reality. Although objects or situations, in and of themselves, may be complicated, they are generally accepted as having "concreteness and tangibility… [however,] even the most concrete situation may be seen from a variety of perspectives… [therefore,] it is useful to assume that complexity is a quality of things *and* of the appreciation that people have of things" (Flood and Carson, 1993, p. 25 – emphasis in original). This definition of complexity places a significant weight on the constructivist paradigm. While the concept of complexity is presented from a wide range of perspectives and from within a variety of disciplines, (Ashby, 1956; Yates, 1978; Clemson, 1984; Jackson and Keys, 1984; Klir, 1985; Flood and Carson, 1993; Warfield, 1994; Weick, 1995), there is general consensus that complexity goes beyond the physical aspects of what the layman often thinks of as complex or complicated. A number of the different perspectives are presented below, after which, a synthesized concept of complexity, as applied in this research, is presented.

Warfield (1994) identifies two components of complexity: situational complexity and cognitive complexity. Situational complexity refers to "those aspects of phenomena that are open to being 'interpreted' by the mind," while cognitive complexity refers to "those aspects...that make interpretation difficult....By convention, the term 'Situation' refers to that which is under study by a human being. The Situation may include human beings, but the particular human being(s) who are studying the Situation are by definition, not part of it" (Warfield, 1994, p. 133). "Together the two components [situational and cognitive] produce complexity which, when overcome, yields to a conceptualization that exhibits Referential Transparency" (Warfield, 1994, p. 152). In many cases, discussions of complexity focus only on the situational component of complexity, completely overlooking the concept of cognitive complexity, thereby eliminating the human mind or differences in perspective as elements of complexity. This is related to the previous comment from Flood and Carson (1993) that complexity is not just about 'things,' but also about how people interpret or see things and situations. This recognizes that "complexity has a somewhat subjective connotation since it is related to the ability to understand or cope with the thing under consideration. Thus a thing that is complex for one person may be simple for someone else...[therefore] we do not attempt to deal with complexities of objects, only complexities of systems defined on objects" (Klir, 1985, p. 325). "Any definition of complexity must recognize the sensitivity of the concept to how the human being is viewed. If the human being has only a limited sphere of perception, and a limited information-processing capability, both in terms of amount of information and rate of processing it, then clearly what is or is not complex in a situation must be assessed in the light of these limits" (Warfield, 1994, p. 134). The concept of the subjectivity of complexity is significant, particularly in light of the discussion in following chapters where a philosophy for complex systems is developed suggesting the need to take a subjective approach.

Warfield's is not the only perspective or concept of complexity. Yates (1978), for example, states, "complexity usually arises whenever one or more of the following five attributes are found: 1) significant interactions; 2) high number (of parts, degrees of freedom or interactions); 3) nonlinearity; 4) broken symmetry; and 5) nonholonomic constraints" (Yates, 1978, R201).

The first two attributes have been covered above, but the attributes of complexity related to nonlinearity, broken symmetry or asymmetry and the existence of nonholonomic constraints require further examination. Nonlinearity, in this instance, is referring to the relationship between elements of a system and is exhibited when at least one of those interrelationships does not follow a linear function. The existence of such relationships is a major indicator of complexity because they cause the system to be much more intractable. "A feature of nonlinear representations is that different starting points will lead to different 'end' points and can cause the model to become unstable... commonly their behavior is counterintuitive, a characteristic of our inability to comprehend complex systems" (Flood and Carson, 1993, p. 29). This counterintuitive nature makes nonlinearity a significant contributor to complexity. The more such relationships exist in the system, the greater the complexity of the system.

Another of Yates' indicators is broken symmetry. To illustrate this attribute, take the example of cell reproduction at the earliest stages of development of a human being. Initially, there is just a collection of cells – symmetrical and with no differentiation among them. However as development continues, differential growth and asymmetry are introduced, resulting in the creation of a distinct, unique creature. “A larger blob of cells is no more difficult to understand than a small blob of cells, it is no more complex… when processes occur that lead to asymmetrical structure and organization, the rise in complexity from a few elements to many elements… is compounded by yet another attribute that makes things more difficult to understand” (Flood and Carson, 1993, p. 30). The key is that asymmetry is a major source of the increased complexity.

The concept of nonholonomic constraints refers to those instances where elements of the system are for some period of time not under central control. Complexity will be higher when parts of the system have a high degree of freedom and “where behavior and control of the parts cannot be easily predicted based on knowledge of the system....[where parts of the system] go off and ‘do their own thing’” (Flood and Carson, 1993, p. 31). The increased autonomy or independence of components or subsystems makes understanding the system very difficult; therefore, increased nonholonomic constraints result in greater system complexity.

Another view of complexity is presented by Weick. In a discussion on the concept of sensemaking, Weick (1995) touches on complexity and how observers attempt to deal with it. He states that “complexity affects what people notice and ignore. [Increased complexity]...can increase perceived uncertainty because a greater number (numerosity) of diverse elements (diversity) interact in a greater variety of ways (interdependence)…with greater complexity goes greater search for and reliance on habitual, routine cues, cues that increasingly mislead” (Weick, 1995, p. 87). While these characteristics of complexity from Weick’s perspective (numerosity, diversity, and interdependence) are not identical to Yates, there is a great deal of similarity between the key points each points out as indicative of complexity.

From the systems discipline, another view is that complexity exists as a continuum that can be separated into three distinct levels - organized simplicity, organized complexity, and disorganized complexity (Weaver, 1948). Exhibit 5 provides a summary of Weaver's levels of complexity.

**Exhibit 5. Weaver's Levels of Complexity**

| Complexity Level | Description |
|---|---|
| Organized Simplicity | Systems at this level of complexity are mostly deterministic and consist of large number of trivial entities or small number of significant entities. These systems may initially appear complex, but can readily be explained in terms of parts. Example: physical laws governing behavior of matter and energy (Flood and Carson, 1993; Clemson, 1984; Klir, 1985). |
| Disorganized Complexity | This range of the continuum contains systems that are mostly probabilistic and consist of many elements (variables) exhibiting a high degree of random behavior. Behavior can be explained or modeled in terms of patterns and can be described statistically. Example: behavior of gas molecules (Flood and Carson, 1993; Clemson, 1984; Klir, 1985). |
| Organized Complexity | This area is between organized simplicity and disorganized complexity on the continuum. Systems at this level typically exhibit a level of richness that cannot be appropriately addressed using the methods of decomposition effective for dealing with organized simplicity or those of probability used in addressing disorganized complexity. Those who attempt to apply such methods at this level of complexity risk oversimplifying the complexity of the system to the point where the richness of the system is lost (Flood and Carson, 1993; Clemson, 1984; Klir, 1985). |

The analytical methods available for dealing with the first two levels of complexity (i.e., analysis by decomposition for organized simplicity and statistical methods for disorganized complexity) are well-developed and work effectively for analyzing systems in these regions of the continuum. However, "they cover the two extremes of the complexity spectrum...a tiny fraction of the whole spectrum.... This means, in turn, that the whole complexity spectrum except its extreme ends is methodologically underdeveloped in the sense that neither analytical nor statistical methods are adequate to cope with it" (Klir, 1985, 330). This point is significant in that it stresses the challenges of dealing with the types of complex systems that have been the focus of this research.

This characterization of the complexity continuum works fine for natural systems and designed physical systems, however, some submit that it does not address the characteristics of 'human activity systems' or 'designed abstract systems' (Checkland, 1981). To fill this gap, the field of cybernetics suggests a fourth level or range, 'relativistic organized complexity,' introduced by Clemson (1984). Systems at this level have both probabilistic and deterministic properties, and this categorization recognizes the interaction of the observer (or observing system) with the system under observation. "The activity of observing... has some influence on the observed system" (Clemson, 1984, p. 21). "The nature of perceived reality is inevitably conditioned by our nature as observing systems" (Flood and Carson, 1993, p. 35). In this characterization, complexity is not an intrinsic property of the observed system, but a function of interaction between the observing (or observer) and the observed. This level acknowledges the cognitive component of complexity presented by Warfield (1994).

Other attributes or principles related to complexity in systems include feedback, holism, self-organization, and requisite variety. Feedback (or circular causality) gives systems the ability to exhibit highly complex behavior, whereby relatively minor changes within or to the system can result in major effects in changes to system behavior. In complex systems where feedback loops exist, the same set of initial system conditions can result in different final states, and conversely, different initial conditions (and different pathways) can result in the same final state (Clemson, 1984; Klir, 1985; Flood and Carson, 1993; Midgley, 2000).

The holistic nature of systems is associated with the concept known as emergence. Systems exhibit holistic behavior because there are characteristics which belong to the system as a whole and don't belong to any of the parts (Clemson, 1984; Klir, 1985; Flood and Carson, 1993; Midgley, 2000). The concept of emergence often brings to mind the overly simplified and overused system premise that 'the whole is greater than the sum of its parts.' However, there is much more to emergence than this simple statement implies. Emergence is a characterization of the phenomenon by which "a human being is not an aggregate of bodily parts. Nor is a business an aggregate of management functions, nor a society an aggregate of social groups. In each case, things come together to form wholes whose properties are different from the parts" (Flood and Carson, 1993, p. 18). The point being that in order for a system to be understood it must be considered as a whole, including all of the interactions and relationships among its parts and subsystems, and how they manifest themselves in overall, holistic system behaviors.

Self organization is the property whereby complex systems organize themselves. Self organizing systems "may continuously change either their structure or their identity, in order to assure their viability - survival - under continuously changing environmental conditions and challenges" (Martinelli, 2001, p. 78). A corollary to the principle of self organization is the concept that complex systems have "basins of stability separated by thresholds of instability" (Clemson, 1984, p. 27). As a result there are certain conditions or states within a complex system that are stable and others that are not, and the system will return to a more stable state unless some force or continuous disturbance is applied to it.

Variety is viewed as being related to complexity in that complexity of system corresponds to the degree of variety of the system under investigation - the higher the variety, the higher the complexity (Ashby, 1956; Beer, 1966; Flood and Carson, 1993). Similarly, variety can be defined as "the number of possible different states of that system" (Clemson, 1984). The law of Requisite Variety says that for a given system and regulator of that system, the capacity attainable by the regulator cannot exceed the variety of the regulator (Ashby, 1956). In other words, the key is the relative complexity of the system and the regulator. From a slightly different perspective, "the variety of the controller must be greater than, or equal to, the variety of the system to be controlled, or the environment to be dealt with. This must be achieved if the system is to have a guarantee of remaining under control" (Flood and Carson, 1993, p. 15). All any regulator can do is deal with those aspects of the system that are aligned with the complexity of the regulator (Ashby, 1956; Clemson, 1984). The law of Requisite Variety can be compared with other laws or principles through which a maximum value was established for a given phenomenon or action. Following this idea, based on Requisite Variety, the regulator or controller would ideally operate at or near its maximum (Ashby, 1956). Because of the complexity involved in the very large system and the constraints imposed by Requisite Variety, system observers, operators, and designers should have "no extravagant ideas of what is achievable" (Ashby, 1956, p. 245). A corollary to the law of Requisite Variety says of regulation within complex systems that the overall regulation of the system results from a cumulative effect, in which one part regulates other part(s) of the system (Ashby, 1956).

Another perspective of complexity looks at a "simple-complex dichotomy," within which the determination whether a system is simple or complex is observer dependent. The distinction will "depend on the observer of the system and upon the purpose he has for considering the system… Often the same system may be seen as being simple or complex, depending upon the problem" (Jackson and Keys, 1984, p. 475). Given this aspect of complexity, the following four additional points contribute to the determination of a system as being complex:

- All attributes of a complex system's parts will not be directly observable
- Any laws or models created to describe the actions of complex system or their different parts can only be probabilistic and not deterministic
- Complex systems evolve over time
- Complex systems exhibit behavioral problems, driven by the strong influences of "political, cultural, ethical and similar factors… [which make] it difficult for the problem solver to fully understand the 'rationale' behind decisions made by actors in the system (Jackson and Keys, 1984, p. 476).

This discussion of complexity has shown that there are many different aspects that must be taken into account in determining the level of complexity of any given system or system problem. However, the most significant concept to take away from this discussion is that some of the primary determinants in system complexity are the worldview, specific purpose, cognitive ability, and interest of the observer. This concept of complexity as being constructed based on the perception or appreciation of a situation or system by an observer provides a foundation for addressing concepts of complex systems and complex system problems. It is important to take away that "as the complexity of a system increases, our ability to make precise and yet significant statements about its behavior diminishes until a threshold is reached beyond which precision and significance (or relevance) become almost mutually exclusive characteristics" (Zadeh, 1973, p. 28). This further supports the contention that conventional, typically quantitative, systems analysis techniques are not well-suited for systems of a high degree of complexity (e.g., those demonstrating relativistic organized complexity).

Methods must be developed to help observers deal with this type or level of complexity so that complex systems can be understood and complex system problems addressed. Accurately capturing system context through a well-defined process of problem formulation is one step toward providing those methods.

## Complex System Problems

Many of the most significant problems facing society today are the product of or are embedded within complex systems. Resolving or even addressing problems such as these requires first understanding the complex system with which the problem is associated and then determining how it might be modified to change the problem situation. "Many of society's problems emerge from processes associated with structures that combine people and the natural environment with various artifacts of man and his technology; these structures can be thought of as systems. Such problems, and the systems of which they are aspects, abound in modern society" (Quade and Miser, 1985, p. 1). This indicates a systems-based problem-solving approach. The key element provided by a systems approach is a holistic perspective of the problem system. The problem system includes "the social and technical elements, their formal and informal relationships, emergent patterns, and the unique context of the problem" (Keating et al, 2001, p. 773). When approaching problems from a systems perspective, two critical points must be kept in mind:

- "problems cannot be isolated from the system that is producing the problematic behavior; and
- the problem system cannot be understood independently from the context within which it is embedded" (Keating et al, 2001, p.773).

According to Keating et al (2001), from the systems perspective, problems or problematic conditions are the product of a complex system, the problem system; and for each specific problem, the problem system is embedded within a unique context. So, a systems-based view of problem solving tells the systems practitioner that instead of addressing problems, a systems view suggests we understand "problem systems in context" (Keating et al, 2001, p. 773).

To add to the confusion, for any given problem or problem system there are always varying perspectives. "One of the most pervasive characteristics of messy problems is that people hold entirely different views on (a) *whether there is a problem, and if they agree there is*, (b) *what the problem is*. In that sense messy problems are quite intangible and as a result various authors have suggested that there are no objective problems, only situations defined as problems by people" (Vennix, 1996, p. 13 emphasis added). As a result of this typical lack of clear problem definition in complex systems problems, the problem-formulation or problem-setting phase of analysis in these situations is critical to the success of the entire effort.

While complex problems such as this, or 'messes' as Ackoff (1974, 1981) referred to them, are no doubt the most difficult to address, they cannot simply be ignored because of this difficulty, for these problems are the issues of most consequence to individuals and to society. "In the varied topography of professional practice, there is high, hard ground where practitioners can make effective use of research-based theory and technique, and there is a swampy lowland where situations are confusing 'messes' incapable of technical solution.... Problems of the high ground ...are often relatively unimportant to clients or to the larger society, while in the swamp are the problems of greatest human concern" (Schön, 1983, p. 42). The result, then, is a situation where the most consequential problems we have to deal with are "wicked problems" (Rittel and Webber, 1973, p. 160) that cannot be readily dealt with using traditional linear, analytical, reductionist approaches; one alternative is a systems approach.

Problems most appropriately addressed using systems-based methodologies are much different from those studied in the fields of traditional science. The scientific or mechanistic approach is one of reduction, where the problem is broken down or decomposed to simplify it so it can be studied and analyzed. This reductionist approach works fine in cases where complexity is sufficiently limited such that it can be simplified, as in the linearization of non-linear models. However, systematic reduction or decomposition of complexity is not a technique the systems analyst can readily employ (Churchman, 1968; Ackoff, 1974). An individual trying to deal with complex systems in such a mechanistic manner "tends to resort to reduction of a complex system into `manageable' parts. Such parts are treated as independent and autonomous. The mechanist assumes that improvement of the parts will result in overall system improvement," but it does not work (Ryan and Mothibi, 2000, p. 377). Specifically, this approach "...fails when a non-linear and/or far-from-equilibrium phenomenon refuses to yield to any simplifications" (Murthy, 2000, p. 78). This clearly indicates that with complex problems, there is a need to a different approach, a systems approach.

The systems analyst's problems "exist in the real world; the phenomena he investigates cannot be taken into a laboratory, and they are usually so entangled with many factors as to appear inseparably linked to them" (Checkland, 1985, p. 151). Some suggest that factors such as these with which problems become intertwined are part of the system context (Keating, 2000; Keating and Sousa-Poza, 2003; Checkland, 1985; Murthy, 2000). Complex systems problems can be compared to the non-equilibrium branch of thermodynamics, specifically in the area known as "far-from-equilibrium…[where] all phenomena are non-linear and entropy production rate is positive. Infinitesimal fluctuations amplify to large oscillations introducing structural changes" (Murthy, 2000, pp. 85-86).

This section has highlighted that the literature points out that many of the most significant challenges the world faces today come from complex system problems, each of which is inextricably linked with a unique complex system and an associated system context. Additionally, these problems are further complicated by the abundance of multiple perspectives, the lack of clear understanding of the exact nature of the problem, and the fact that in most cases it is not readily apparent what the solution might look like. A general theme that can be drawn from the literature is that complex system problems and the associated problem systems are inherently difficult to define. This suggests some connection with the process of problem definition or problem formulation, which is discussed in the next section.

**Problem Formulation**

Within the domains of systems analysis, systems engineering, other system approaches, and a wide range of other disciplines associated with dealing with problems, the literature (Bergvall-Kareborn, 2002a, 2002b; Murthy, 2000; Keating et al, 2003b, 2003c; Hitchins, 2003; Checkland, 1985; Gibson, 1991; Farr and Buede, 2003; Dery, 1984) agrees that one of the most important factors in addressing complex problems is being able to initially understand and clearly articulate the problem. Exhibit 6 illustrates the breadth of different concepts related to problem formulation, which should be included in a discussion of system context. It also shows how this research brought these concepts together into a single framework for context within complex systems and complex system problems.

**Exhibit 6. Literature Related to Problem Formulation and Context**

| | | Concepts Related to Problem Formulation and Context | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Author** | **Domain** | **Multiple views of problem (worldview)** | **Define/Formulate/Frame the problem** | **Problem as objective entity** | **Problem as constructive or interpretive entity** | **Rich pictures** | **Generalize** | **Context/Contextual Integrity** | **Context of... Problem/situation/study** | **Problem Setting** | **Frame the Context** |
| **Bergvall-Kareborn (2002a, 2002b)** | Systems Analysis | X | | | X | X | | X | | | |
| **Vennix (1996)** | Systems Analysis | X | | | | | | | | | |
| **Dery (1984)** | Policy Analysis | | X | X | | | | | | | |
| **Checkland (1985)** | Systems Analysis | X | | | X | X | | X | X | | |
| **Gibson (1991)** | Systems Analysis | | | | | | X | X | | | |
| **Bowen (1998)** | Systems Analysis | | X | | | | | | | | |
| **Quade and Miser (1985)** | Systems Analysis | | | | X | | | X | X | | |
| **Schön (1983)** | Systems Analysis | | | | X | | | X | | X | X |
| **Hitchins (2003)** | Systems Engineering | | X | | | | | | | X | |
| **Keating et al (2001, 2003a, 2003b, 2003c); Keating and Sousa-Poza (2003)** | Systems Engineering / SoSE | | X | | | | | X | X | | |
| **Farr and Buede 2003)** | Systems Engineering | | X | | | | | | | | |
| **Crownover (2005)** | | X | X | X | X | X | X | X | X | X | X |

While many different methodologies have been put forth for addressing complex system problems, there is strong consensus across these various approaches that problem definition (also referred to as identification, formulation, setting, or framing) is "an essential step in the solving process" (Dery, 1984, p. 2). However, while problem definition is a common element within proposed processes for complex system problem solving and its importance is generally accepted, there is a lack of clarity as to what problem definition is or how to do it. "Whether we seize, set, define, discover, or formulate a problem, we are not certain of precisely what we are doing; nor is it obvious that we understand the object of such pursuits" (Dery, 1984, p. 14). The concept of defining or framing problems remains ambiguous without a clearly discernable foundation in rigorous research.

According to Gibson (1991), the importance of contextual integrity cannot be overemphasized. System context is considered so critical that is was highlighted as one of the "guiding systems principles for SoSE [System of Systems Engineering] methodology development" (Keating and Sousa-Poza, 2003, p. 3). In many cases, "the technical aspects of a problem are overshadowed by the context (circumstances, conditions, factors) within which the problem system is embedded. Success [in dealing with the complex system problem] will be as much determined by adequately addressing the contextual problem drivers as the technical problem drivers" (Keating et al, 2003a, p. 2-5). However, the concept of system context is not developed further in the literature. Complex system problems are

> "problems in which many elements interact as part of what, by definition, is conceived to be the system associated with the problem [involving] numerous interrelated but disparate elements.... The complexities of each of these problems and the large numbers of people concerned with how they are solved, make it clear that many decision-makers are involved, many people's interests are affected, and many constituencies may have competing objectives... moreover, [these] ...problems are attended by many uncertainties" (Quade and Miser, 1985, p. 12-13).

The idea that understanding the contextual aspects of a system is key to problem formulation is further indicated by the assertion that complex system problems typically "arise from a problem area or nexus of problems rather than a well-defined problem; if the context is sufficiently complicated, it may never get much beyond this without a major effort" (Quade and Miser, 1985, p. 17).

Understanding system context is not only a critical element of understanding the system under study, but also is crucial to the development of a successful systems-based approach. In systems-based approaches, the "disciplines involved, methods used, the forms of communication adapted, and the schedule for the work all respond sympathetically to the needs of the context..." (Quade and Miser, 1985, p. 18). It is critical to appreciate that complex system problem definition is not simply a matter of developing "a descriptive definition, for it does not merely describe but also chooses certain aspects of reality as being relevant for action in order to achieve certain goals" (Dery, 1984, p. 35). So, the importance of system context goes beyond its role in defining the system or problem and is also related to the way context contributes to the selection or development of an approach for addressing the complex system problem(s) of interest.

Problem definition is an integral part of the work of those considering complex systems, "perhaps the most crucial part, but it has traditionally been the part least well codified in the canons of methodology and 'normal science.' There is, in fact, no orderly or prescribed way to do it" (Rein and White, 1977, p. 263). With few exceptions, "the question of what is a problem – the process called problem definition and what one should expect to see at the end of this process..." has not been addressed (Dery, 1984, p. 2). So even given the critical importance of problem formulation and problem system context as delineated above, there has been a lack of rigorous research applied to determining how to construct and articulate context as part of the complex system problem definition process. "As teachers, consultants, and researchers, we often warn against the hazards of poor problem formulation. We praise 'systems thinking,' ridicule the tendency to do more of the same, and leave the rest to creative minds" (Dery, 1984, p. 3).

This section illustrates that there is general agreement that any systems-based effort to address or resolve a complex system problem is founded upon the formulation of the problem, and a critical element in the formulation process is the establishment of complex system context. However, the concept of system context remains ill-defined. Systems literature and the larger systems body of knowledge lack an agreed upon or clearly established conceptualization of system context; furthermore, there is no accepted approach for constructing it, relegating the development of this essential part of understanding a complex system problem to a range of extemporaneous approaches.

**The Concept of Context**

This section begins the process of developing a well-supported and fully defensible perspective of complex system context by first presenting a discussion of the concept of context from a broader perspective. The definitions below, taken from several dictionaries, provide a broad background for the following discussion of context. Context is defined as:

- **the set of circumstances or facts that surround a particular event, situation, etc.** – *(Webster's Encyclopedic Unabridged Dictionary of the English Language, 1995)*
- **the immediate environment; attendant circumstances or conditions; background** – *(The World Book Encyclopedia Dictionary, 1965)*

– **associated surroundings, setting** – *(Webster's Dictionary & Thesaurus, 1995)*

After reviewing a range of discussions on context, it is clear that the concept of context is reflexive... in other words the meaning and significance of context has to be contextualized within a specific situation, domain, discipline or practice. The following discussion of the concept of context draws upon multiple perspectives, focusing on the variations in usage and implications of context.

In biographical research methods the need for an author to provide the proper context for the subject of the biography is emphasized for readers to be able to truly understand the 'hero' of the biography. Context in this perspective is primarily focused on social context – "Context refers to the particular conditions that prevail in any society at any moment in time" (Smith, 1994, p. 299). This perspective of context is a relatively high-level, all-inclusive view of the concept. It does not specify or imply a direct relationship between the subject of the biography and any particular elements of social context. Context in this sense is more closely in line with the concept of environment as an all-inclusive set of 'things' in a given setting outside of the boundary of a system (Flood and Carson, 1993; Passmore, 1988; Taylor and Felten, 1993) or organization (Moorehead and Griffin, 1995).

Within the domain of communications, particularly written communication, the concept of context plays a very direct and significant role. When trying to understand written communication, "...there is no 'original' or 'true' meaning of a text outside specific historical contexts" (Hodder, 1994, p. 394). As the spoken word is transformed into written form, the dangers of misinterpretation increase due to the separation of text from context. "Words are, of course, spoken to do things as well as to say things – they have practical and social impact as well as communication function. Once transformed into a written text the gap between the 'author' and the 'reader' widens and the possibility of multiple reinterpretations increases. The text can 'say' many different things in different contexts" (Hodder, 1994, p. 394). This potential ambiguity makes it absolutely essential for the interpreter (the reader in this case) "to identify the contexts within which things had similar meaning. [Unfortunately, however] The boundaries of the context are never 'given'; they have to be interpreted" (Hodder, 1994, p. 399). Similarly, in interview research, in order for researcher and respondent to create "sharedness of meanings," the parties must ensure they commonly "understand the contextual nature of specific referents" (Fontana and Frey, 2000, p. 660).

In conducting qualitative inquiry in general, context plays a major role in almost all of the various analytical approaches. Researchers must understand the importance of context and how integral it is to being able to understand and interpret social action. Two important properties of social action must be taken into consideration by those conducting research within interpretivist and social constructionist paradigms.

> "First, all actions and objects are 'indexical;' they depend upon (or 'index) context. Objects and events have equivocal or indeterminate meanings without a discernible context. It is through contextualization that practical meaning is derived. Second, the circumstances that provide meaningful contexts are themselves self-generating. Each reference to, or account for, an action… establishes a context… for evaluating the self-same and related actions…. Practical reasoning, in other words, is simultaneously in and about the settings to which it orients, and that it describes. Social order and its practical realities are thus reflexive" (Gubrium and Holstein, 2000, p. 491).

What this implies is that without understanding and articulating context, there is no way for any observer (whether an observer of the system or an actor within it) to know unequivocally the meaning of actions, events, or even objects.

A very interesting perspective on context and contextual sensitivity is found in discussions within the domain of public administration, specifically regarding decision making.

> "An awareness of the contextual conditions which affect the arranging of moral priorities is an essential mental attitude for the moral public servant. [For example,] the moral virtues of the Boy Scout oath are widely accepted in the United States. But, as Boy Scouts get older, they are faced time and again with the disturbing fact that contexts exist within which it is impossible to be both kind and truthful at the same time. Boy Scouts are trustworthy. But what if they are faced with competing and incompatible trusts (e.g., to guard the flag at the base or succor a distant wounded companion)? Men should be loyal, but what if loyalties conflict?" (Bailey, 1992, p. 494).

While this view of public administrators may be disheartening, it reinforces a very important aspect of the concept of context that has been presented earlier – without a discernible and clearly understood context, the meaning of actions, events, and objects (including organizations, systems) remains ambiguous and incomprehensible.

Tying the discussion on context to the research methodology used in this research, context is also an important part of the grounded theory method. Within grounded theory context is defined as "The specific set of properties that pertain to a phenomenon; that is, the locations of events or incidents pertaining to a phenomenon along a dimensional range. Context represents the particular set of conditions within which the action/interactional strategies [i.e., those actions devised by an actor to respond to a phenomenon] are taken" (Strauss and Corbin, 1990, p. 96). This perspective of context is much more abstract than those presented earlier, but it captures the concept that context is a necessary part of being able to understand any phenomenon. This emphasis on the importance of context or context-centered knowledge is indicative of the interpretivistic side of grounded theory, which counter-balances some of the grounded theory method's more positivistic tendencies. Some argue that within the positivistic paradigm, the influence of context is downplayed. "The approach of positivistic research to generalization has been to abstract from context, average out cases, lose sight of the world as lived in by human beings, and generally make the knowledge impossible to apply" (Greenwood and Levin, 2000, p. 97). While the grounded theory method's inclusion of context as a key element for consideration provides strength due to the richness of the data and analysis from which the resultant theoretical constructs emerge, the level of specificity provided by a highly contextual research approach also presents a challenge to generalizability. These two views must be balanced against one another.

As presented from systems literature earlier, system context is pivotal in developing an understanding of the system of interest. This section has demonstrated that from a broader perspective, context is a critical concept across a wide range of disciplines and domains of study. In all of these areas, context is a vital element of establishing meaning and sharing understanding of everything around us, and in this discussion context is closely linked to the concept of the cognitive component of complexity. It is this fundamental role that makes understanding context so important to our ability to analyze or engineer complex systems. The next section further develops the concept of context from a systems perspective.

**Context within Complex Systems**

Having framed context at a general level, the focus is now narrowed to context within the domain of systems and systems-based methodologies. As presented earlier, there is general agreement in the literature within the systems domain that one of the most fundamental elements of addressing complex problems is to initially understand and clearly articulate the problem and the problem system. Drawing upon the previous discussion about context, it can be seen that achieving the requisite understanding of the problem system must include an accounting for context.

It is generally accepted within the domain of systems approaches that when dealing with complex (messy) problems, the focus of the analysis must initially be on properly setting the problem rather than solving it:

> When the emphasis is placed "on problem solving, we ignore problem setting, the process by which we define the decision to be made, the ends to be achieved, and the means by which may be chosen. In real-world practice, problems do not present themselves to the practitioner as givens. They must be constructed from the materials of problematic situations which are puzzling, troubling, and uncertain. In order to convert a problematic situation to a problem, a practitioner must...make sense of an uncertain situation that initially makes no sense. When we set the problem, we select what we will treat as the 'things' of the situation, we set the boundaries of our attention to it, and we impose upon it a coherence which allows us to say what is wrong and in what directions the situation needs to be changed. Problem setting is a process in which, interactively, we name the things to which we will attend and *frame the context in which we will attend to them*" (Schön, 1983, p. 39-42 – emphasis added).

Again, the emphasis must be placed on defining the problem. "It should be thoroughly examined before similar cyclical, recursive, reflective processes come into play on the 'solution' and implementation phases of the inquiry" (Bowen, 1998, p. 175). When done properly, a systems-based approach always includes consideration of the problem system context. "It includes consideration of all of the stakeholders, non-users as well as users" (Gibson, 1991, p. 13). Gibson (1991) refers to the challenge of problem formulation as 'generalizing the question.' The problem (or question) being addressed "must be generalized to phrase it correctly and even more importantly, to place it properly in context. Lack of contextual integrity often frustrates planners who limit their concerns to technical solutions in socially relevant problems" (Gibson, 1991, p. 57). "The systems analyst begins his work cautiously, because his initial aim must be to appreciate the context...without imposing a rigid structure on it" (Checkland, 1985, p. 153). In addition to simply pointing to the pivotal role context plays in the problem definition process, these comments also indicate that an appreciation for system context must be attained early and maintained throughout the analysis process.

As the complexity of problems or problem systems increases, there is a concomitant increase in the importance of analyzing and accounting for context.

> "Contextual analysis facilitates a more holistic representation and consideration of the problem.... [In the world today] emerging complex systems problems are suffering from a much higher level of contextual influence.... In many cases, it might be argued that the contextual issues overshadow the technical issues in a complex system problem. Context includes those factors, conditions, and circumstances that both enable and constrain development of holistic system solutions to complex problems" (Keating, 2000, p. 2).

This illustrates the crucial role of contextual analysis.

Determining system context is an integral part of any systems effort and as such, "it should be counted a cardinal sin of omission if [the approach taken] does not specify the context...within which alone its concepts and solutions have validity" (Chacko, 1976, p. 90). Systems-based approaches "cannot conform to an accepted, predetermined outline, but must respond to the conditions in the problem context and exploit such opportunities for assistance to decision makers as it may offer..." (Quade and Miser, 1985, p. 18). Not only is capturing system context necessary for actually understanding the system, it is a primary factor in determining the appropriate systems-based approach.

Murthy (2000) compares the requisite level of insight of the systems analyst to that of an artist – "[a poet's] literary style of prose...the instinct of an artist...and the stance and style of a musician." While this may seem extreme, the point is that understanding of complex systems and complex system problems is not something that can be achieved through cursory or superficial analysis, neither is it achievable through employment of some rote process. When an analyst knows a system to this level, "Complex situation, context, and problem descriptions will then have concreteness of physical objects with embellishment of subjective feelings and experiences" (Murthy, 2000, p. 77). In considering how to understand complex systems, the systems scientist or complex system problem-solver has to have great insight into the context of the systems they are trying to understand and must be able to comprehend and interpret the system context.

A systems concept related to context is that of a system's environment. In some discussions, such as in sociotechnical systems/organizational literature, the concepts of environment and context are linked together. "All organizations exist in the context of other organizations and larger systems… It is convenient to speak of the totality of systems surrounding and influencing the focal organization [or system] as that organization's environment, realizing, of course, that the environment of any organization is immensely complex and continuously changing" (Passmore, 1988, p. 7).

As discussed above, understanding the system's context is an essential part of being able to understand and deal with complex systems and associated problems because of the interdependence between system and environment. "System theorists and organizational designers must adopt a view of the environment as transitory and shifting, demanding a more strategic interdependence between the organization and its context in which influence occurs in both directions. Organizations [systems] must be viewed as capable not only of sensing and responding to the demands of the environment, but also of transforming those demands" (Passmore, 1988, p. 12). According to Taylor and Felton (1993), identifying the system boundary(ies) specifies the system's environment by default, because the environment is all that lies outside of the boundary(ies). When discussing the concept of goodness of fit between a system and its environment, Taylor and Felton (1993) continue that there is need to identify and compare the system with those elements of the environment considered relevant primarily to assess alignment with regard to expectations, trends, etc. As discussed earlier, where the concept of system context is addressed in systems literature (Gibson, 1991; Keating, 2000; Keating et al, 2003a, 2003b; Keating and Sousa-Poza, 2003), it is depicted differently from the concept of system environment. The primary distinguishing factors between these two closely linked concepts are: 1) unlike the system's environment, system context is not defined by the line of demarcation imposed by the system boundary; 2) system context is not all inclusive in the same way environment is defined (e.g., the totality of systems surrounding the system Passmore (1988); and everything outside of the boundary Taylor and Felton (1993)); and 3) system context includes aspects of the environment, aspects of the system, and aspects of their interactions. Similar to the contextual concept presented earlier by Gubrium and Holstein (2000), system context is self-generating in that the actions and elements of the system become a part of the context for understanding itself. Therefore, while the concepts of environment and context are closely related, there is a distinguishable difference, which will be captured in the research perspective of system context.

The synthesis of systems literature presented in this section was focused on that portion of the systems body of knowledge relevant to complex system context. In so doing, a number of themes were found to be germane to this research. Building upon basic principles and concepts related to complexity and systems theory, the concepts of complex systems and complex system problems were then developed. The synthesis then looked at problem formulation within the disciplines of systems engineering and systems analysis, and the role context has in that process. Lastly, the section developed the concept of context from a general perspective and then narrowed the focus to context in complex systems. The next section presents a critique of the literature as presented in this synthesis.

## LITERATURE CRITIQUE

This section discusses the various segments just presented in the synthesis of literature and points out the key common conceptual threads that run through the literature. It will then highlight shortcomings or problem areas where there are holes or gaps in the body of knowledge, or where the relationships between various concepts are not clearly defined or established.

The overarching theme of the literature reviewed in this chapter can be summarized as follows. Complex systems and complex system problems are the source of some of the most significant challenges facing society today. In order to meet these challenges, approaches must be available for addressing and resolving these problems. One of the requisite elements of any such approach is being able to identify and understand the context of the system under study.

The discussion of literature related to complexity pointed out a number of key aspects that must be considered in this discussion, the most important being that complexity is a construction. While this point is presented very clearly in the literature on complexity, the importance of this aspect of complexity is not highlighted as it should be within the discussions on complex systems and complex systems problems. Failing to recognize this aspect of complex systems and complex system problems results in ambiguity regarding systems context and its importance in understanding complex systems and complex system problems. Gleaning this from the synthesis, helps to illuminate that complex system context should be approached constructively or interpretively.

Whether called problem formulation, problem definition, system definition, discover, or some other term, the process of clearly delineating the complex system and/or complex system problem is agreed within systems literature as being the first (or an early) step that must be taken in addressing a complex system or problem. However, as was pointed out by various sources in the literature, the whole area of problem formulation has not had the benefit of rigorous research that would help to codify how it is to be done, or even what it should be producing.

Within the systems literature, it is clear that of the many aspects of a complex system that must be considered in any analysis process, the system's context is one of the key elements that must be addressed in order to even begin to comprehend the system or the problem, and how to approach it. The importance of establishing system context is identified, but the concept is not developed any further. There is no discussion of what context is, how to identify it, how to represent it, what common attributes it exhibits across various systems, what criteria might used to evaluate it, etc. This hole in the systems literature indicates a need to further expound upon the concept of complex system context.

The conceptual holes or gaps within the systems-related body of knowledge regarding complex system context, as well as the lack of rigorous research in areas related to complex system context point to the need for further development of the concept of complex system context. This critique clearly indicates that in order to advance systems-based approaches to dealing with complex systems problems, the idea of complex system context must be expanded and elucidated, which is the focus of this research.

## RESEARCH SETTING FOR COMPLEX SYSTEM CONTEXT

The purpose of this final section of Chapter II is to frame the research within the literature by developing a characterization or perspective on complex system context. This characterization then formed the foundation for developing the research methodology.

Development of this system context perspective started by drawing on broader concepts of context. A fundamental aspect of context is the notion that true meaning is unattainable without identifying and understanding contextual boundaries, and that contextual boundaries are not givens but must be interpreted or constructed by the researcher/observer. This relationship between context and meaning not only refers to the meaning of a specific item of text (as pointed out by Hodder, 1994), but also applies equally within the systems domain as pointed out by Schön (1983) when he refers to having to construct problems from situations and frame the context in which they exist.

The idea that context is reflexive is another integral part of the systems context perspective for this research. As the meaning of an action or situation (or system) becomes contextualized, that action itself becomes part of the context. Applying this in the systems domain indicated that the system and its associated activities, actions, relationships, etc. are not only provided meaning by system context, but they are part of the system context and help further develop system meaning. Thus the system and system context are inextricably linked in that each significantly influences the defining characteristics and attributes of the other. This supports the fundamental idea that in order for an observer to understand a system, context has to be fully constructed, but it expands it by saying that in order to understand context, the observer must contemplate the system as a whole.

The discussion on context in moral priorities is significant in that it clearly showed that positivistic concepts of a true reality or of black and white criteria rarely work within in context-laden or context-dependent situations, actions, or objects. This observation plus the concept of context-centered knowledge made it clear that entities such as contextually rich complex systems cannot be adequately or accurately captured through a positivistic approach.

Within the grounded theory method, context is presented as a set of properties pertaining to a phenomenon, which locate characteristics of a specific phenomenon along a dimensional range. There is a strong affinity between this concept of dimensional properties and the way Keating (2000) posits that system context consists of factors, conditions, and circumstances that enable and constrain a system. From this perspective, context can be thought of as properties or attributes of a system and/or its environment, and can be represented by some dimensionally definable criteria.

As discussed earlier, the relationship between environment and context is one that must be addressed in developing this system context perspective. Considering the discussion of environment and boundaries from a sociotechnical systems perspective, and linking it back to the discussion of constructing context, the perspective taken in this research was that context is a construction which in addition to capturing other properties of the system, captures the key elements of the environment as they are enacted in contact with and interaction with the system (Weick, 1995). From the earlier example, the environment includes all of the systems outside of the organizational (system) boundary – e.g., government systems, national systems, ecological systems, transportation systems, etc. These systems are all part of the environment, but the systems themselves are not part of context of the system of interest. Rather, the system context includes how the actions of the government system enables or constrains the system in carrying out its purpose.

In summary, taking into account the preceding discussion of various aspects of complex systems, complex systems problems, and complex system context, it was considered essential, prior to moving forward, to establish a research perspective of complex system context for use in the planning and development of this research. The research perspective of complex system context is:

- Complex system context includes events, incidents, factors, settings, or circumstances that in some way act on or interact with the system, perhaps as enabling or constraining factors.
- Complex system context includes an "enacted" environment, which captures system/environment interactions and interdependencies (Weick, 1995). However, system context and system environment are conceptually distinguishable.
- Complex system context is a construct or interpretation of properties of a system that are necessary to provide meaning to the system, above and beyond what is objectively observable.
- Complex system context is reflexive in nature, resulting in context further defining the system while the elements of the system are part of the self-same context.
- Complex system context does not have a true reality or there is no correct interpretation of context. The systems principle of complementarity applies equally to system context as to the system itself.

**CHAPTER SUMMARY**

This chapter has presented a thorough review of relevant literature in support of this research. The pertinent literature was discussed and synthesized, developing a number of overarching themes and ideas. A critical analysis of the literature was then given, which pointed out a number of areas where the literature lacked clarity, or where key aspects of complex systems related to the concept of context were underdeveloped or missing entirely. Lastly, a research setting was presented to show how the treatment of complex system context was being approached within this research effort. This included development of a research perspective of complex system context. Chapter III expands the discussion of the research by providing a research philosophy or perspective.

# CHAPTER III

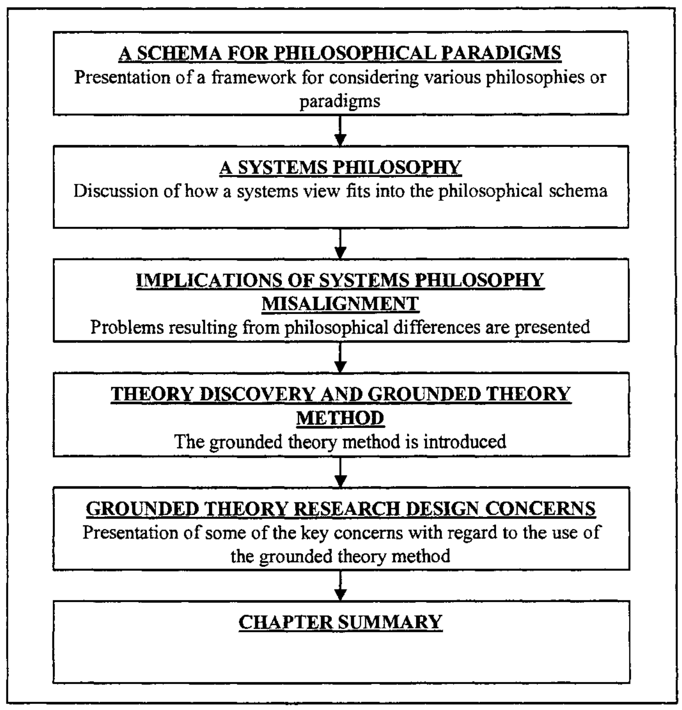
# RESEARCH PERSPECTIVE

In conducting rigorous research (regardless of the discipline, research area or specific research topic), it is essential to establish a clear and common understanding of the philosophical and paradigmatic underpinnings of the effort. This chapter begins by presenting a schema for philosophical paradigms. Not intended to be an exhaustive treatise on philosophy, this discussion only delves into the topic enough to lay the groundwork for the next discussion, the development of a philosophy of systems. This discussion presents how systems views fit into the philosophical schema and establishes an ontological and epistemological basis for studies conducted within the domain of systems-based approaches.

To emphasize the importance of establishing a common philosophical understanding, issues are discussed that could potentially arise should there be misalignment, misunderstanding, or lack of synchronization of systems philosophies amongst various parties to any research endeavor. The philosophical perspective under which this research was conducted is also discussed.

As stated above, the importance of establishing and clearly articulating the philosophical underpinnings of any research cannot be overemphasized. Understanding any philosophical aspects associated with the specific research methodology being applied is just as important as understanding the philosophical paradigm under which the research was conducted. Following presentation of the systems philosophy, the discussion shifts to grounded theory method, including the theoretical and philosophical foundations of grounded theory research, the rationale behind the selection of this particular approach for this research, and some of the concerns that have been raised regarding the method. Exhibit 7 provides a layout of the contents of Chapter III.

**Exhibit 7. Chapter III Layout Diagram**



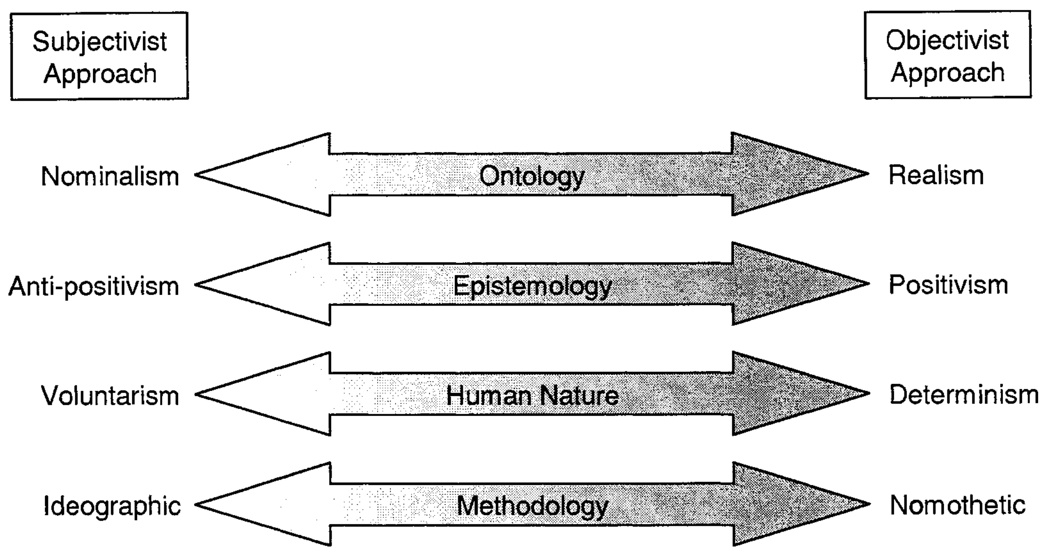

## A SCHEMA FOR PHILOSOPHICAL PARADIGMS

There is significant agreement in the literature on the importance of understanding the philosophical foundations of researchers and research efforts (Bateson 1972; Sutherland 1973; Flood and Carson 1993; Denzin and Lincoln 1994, 2000a, 2000b; Lincoln and Guba 2000). This section presents a schema for articulation of philosophical paradigms, which can be used when considering the philosophical basis of various works of research.

Denzin and Lincoln (2000) submit that the researcher "approaches the world with a set of ideas, a framework (theory, ontology) that specifies a set of questions (epistemology) the he or she then examines in specific ways (methodology, analysis)" (Denzin and Lincoln, 2000a, p. 15). They later add that all researchers (particularly in the social realm) are philosophers and are guided by a set of abstract principles. "Those principles combine beliefs about ontology (What kind of being is the human being? What is the nature of reality?), epistemology (What is the relationship between the inquirer and the known?), and methodology (How do we know the world, or gain knowledge of it?)" (Denzin and Lincoln, 2000b, p. 159). According to Bateson (1972), researchers are "bound within a net of epistemological and ontological premises which – regardless of ultimate truth or falsity – become partially self-validating" (Bateson, 1972, p. 314). Sutherland (1973) refers to epistemological and ontological issues as "the premises under which investigation, analysis, and model-building take place – in effect, they are what we might loosely refer to as *transparent axiological predicates* of scientific enterprise" (Sutherland, 1973, p. 56 – emphasis in original). All of these observations point to the need for a way of identifying and representing the range of philosophical paradigms under which rigorous research is conducted.

Burrell and Morgan (1979) present a comprehensive and well-articulated discussion on philosophical concepts and considerations that are applicable to social, as well as systems-based research. Coming from the broader perspective of the social sciences, their treatise addresses the philosophical and paradigmatic assumptions that "underwrite different approaches to social science" (Burrell and Morgan, 1979, p. 1). They also present a framework for understanding these philosophical concepts based on a given research paradigm's position along four dimensions related to: ontology, epistemology, human nature and methodology. Exhibit 8 (adapted from Burrell and Morgan, 1979) represents these dimensions as they relate to the nature of social science.

**Exhibit 8. Burrell and Morgan's Subjective-Objective Dimension**




Based on this conceptual foundation, it becomes clear that before discussing the specifics of an approach to the research in question or any research effort, the nature of the assumptions that must be made in each of these areas (i.e., their dimensionality along each of the axes depicted in Exhibit 8) must be discussed to understand the range of philosophical positions or beliefs of researchers and how those positions come together and interact to help shape the direction, interpretation, and even the outcome of the research. Burrell and Morgan (1979) posit that each of these four axes forms a continuum between two extremes which they categorize as being representative of two overarching paradigms or approaches – the subjective approach and the objective approach. The following discussion presents the four philosophical areas of consideration (ontological, epistemological, human nature, and methodological), and describes the two extreme positions for each area as related to the two paradigms.

***Ontological*** – This area covers assumptions about the reality of any phenomena, and the things that make up our world. It asks "whether the 'reality' to be investigated is external to the individual – imposing itself on the individual consciousness from without – or the product of individual consciousness" (Burrell and Morgan, 1979, p. 1). Is reality 'out there,' or is it constructed in the mind of the observer? The extremes of ontology are realism and nominalism.

- **Realism:** Under realism, "the social world external to the individual cognition is a real world made up of hard, tangible and relatively immutable structures" (Burrell and Morgan, 1979, p. 4). "Reality is external to the individual imposing itself on individual consciousness; it is a given 'out there,' and is of an objective nature" (Flood and Carson, 1993, p. 247).
- **Nominalism:** The subjective extreme of the ontological continuum, nominalism, purports that "reality is a product of individual consciousness, a product of one's own mind or of individual cognition" (Flood and Carson, 1993, P. 247). According to the nominalist, "the social world external to the individual cognition is made up of nothing more than names, concepts and labels which are used to structure reality" (Burrell and Morgan, 1979, p. 4).

While discussing the ontological aspects of subjective-objective dualism, Einstein (1934) stated:

> "The belief in an external world independent of the perceiving subject is the basis of all natural science. Since, however, sense perception only gives information of this external world or of 'physical reality' indirectly, we can only grasp the latter by speculative means. It follows from this that our notions of physical reality can never be final. We must always be ready to change these notions...in order to do justice to perceived facts in the most logically perfect way" (Einstein, 1934, cited in Midgley 2000, p. 43).

This not only suggests that Burrell and Morgan's ontological axis is truly a continuum and is not simply a matter of black or white extremes, but also points out that regardless of whether one asserts that reality is absolute or not, as long as humans are required to sense and understand it, there will be some degree of speculation, nominalist subjectivity, involved – a concept not generally considered within the domain of physics at the time of Einstein's writing (Midgley, 2000).

***Epistemology*** – Epistemological assumptions consider the basis of knowledge. What kinds of knowledge can be acquired? Is knowledge something that is hard, concrete, and tangible; or is knowledge soft, subjective and experientially-based? How we can determine true from false? In fact, even considering that a dichotomy of 'true' and 'false' exists one is presuming a certain epistemological position (Burrell and Morgan, 1979). The extremes of the epistemological axis are as follows:

- **Positivism:** The positivistic view supports the notion that it is possible to explain what happens in the world through defining or determining "regularities and causal relationships between its constituent elements… the growth of knowledge is essentially a cumulative process in which new insights are added to the existing stock of knowledge and false hypotheses eliminated" (Burrell and Morgan, 1979, p. 5).

- **Anti-Positivism:** The anti-positivistic perspective is opposed to the idea that it is meaningful to search for laws or underlying regularities or patterns, but rather embraces the more relativistic view which is "understood from the point of view of the individuals who are directly involved in the activities which are to be studied" (Burrell and Morgan, 1979, p. 5).

***Human Nature*** – The question of human nature is primarily focused on understanding how human beings relate to or with their environment (Burrell and Morgan, 1979). This continuum extends between the following two extremes:

- **Determinism:** A deterministic view sees human beings from a mechanistic perspective, which sees "man and his activities as being completely determined by the situation of 'environment' in which he is located" (Burrell and Morgan, 1979, p. 6).
- **Voluntarism:** Voluntarism, on the other hand, suggests that human beings are completely "autonomous and free-willed" (Burrell and Morgan, 1979, p. 6) creatures that are capable of creating or influencing their environment or the situation in which they find themselves.

***Methodology*** – The methodological assumptions or choices made by a researcher are influenced by where the researcher chooses to exist (or is determined to exist) along the spectrum of each of the philosophical concepts presented above. Methodological assumptions have to do with how we attempt to investigate and gain knowledge about our world (Flood and Carson, 1993). The objective-subjective extremes for methodology are:

- **Nomothetic:** The objective perspective of the methodological assumptions views that research should be based upon "systematic protocol and technique" (Burrell and Morgan, 1979, p. 6), and the underlying methodologies should strive to identify universal laws that define an observed reality.
- **Ideographic:** An ideographic view assumes that "one can only understand the... world by obtaining first-hand knowledge of the subject under investigation" (Burrell and Morgan, 1979, p. 6). This view questions external reality and highlights the importance of "understanding the complex world of lived experience from the point of view of those who live it." The emphasis is on the "world of lived reality and situation-specific meanings" (Schwandt, 1994, p. 118).

When applying the preceding discussion of philosophies to systems perspectives, there is a noticeable bifurcation as to where along the philosophical axes various systems approaches fall. Some systems-based methods align very clearly on or near the objectivist end of the spectrum (realistic, positivistic, deterministic, nomothetic), while other systemic approaches ascribe to paradigms that are much more in line with the subjectivist philosophical assumptions (nominalistic, anti-positivistic, voluntaristic, ideographic). On the surface, it appears illogical to consider approaches based on such dichotomous philosophical conceptualizations or paradigms as both being 'systems-based.' While this philosophical split indicates a dichotomy of systems views as discussed below, there is a common thread. "What they both have in common, however, is the focus on comprehensiveness as an *ideal*" (Midgley, 2000, p.

36 – emphasis in original). Though they may differ as to whether comprehensive knowledge of the system is absolute or relative, their goal is to continually grow in insight.

Checkland (1981; 1985) points out that one of the distinguishing lines of demarcation between these two paradigms is the differentiation between 'hard' and 'soft' systems-based problem-solving approaches. The terms 'hard' and 'soft' systems are applied in systems literature "analogously to the conventional terms 'hard science,' i.e., rigorously quantitative such as mathematics, physics, and chemistry, and 'soft science,' i.e., non-quantitative such as psychology and sociology" (Gibson, 1991, p 24). Understanding this distinction is essential to understanding the bifurcation of systems philosophies.

When applying systems methods created to understand hard systems/problems, researchers approach from a perspective "that leads to problems having relatively sharp boundaries and well-defined constraints. Appropriate information flows for the decision process are capable of clear definition, and, most important, what the analyst will recognize as 'a solution' to the problem is clear" (Checkland, 1985, p. 155). These approaches are influenced very heavily by the strong positivistic epistemology of an objectivist paradigm.

This is much different from the worldview of those who address soft systems/problems in which the elements listed above (boundaries, constraints, information flows, solution set) "are themselves problematical. Here many objectives are unclear, some important variables are unquantifiable, and the analysis will necessarily have to include examining the value systems underlying the various possible objectives" (Checkland, 1985, p. 155). This perspective is consistent with the 'axiological component' of systems engineering identified by Gibson (1991). This concept "implies an underlying set of values" pertaining to the system, which "may be implicit and most probably incomplete and conflicting" (Gibson, 1991, p. 63). This description of 'soft' systems approaches is indicative of the influence of a more constructivist/interpretivist perspective of systems.

While the differentiation between hard and soft is often made to illustrate the range of systems perspectives, there is rarely a clear-cut distinction. "A given study is likely to contain both hard and soft aspects: real-world problems rarely fit entirely into any predefined category" (Checkland, 1985, p. 155). This is important to note because the paradigmatic differences make it essential for the researcher to recognize and clearly distinguish between these two concepts. Flood and Carson (1993) agree with the Checkland's initial concerns regarding these opposing paradigms, but then further the discussion by referring to a view of complementarism, which suggests that different "types of systems thinking can operate together in a complementarist fashion…[which] refutes the hard-soft argument" and constructs a framework under which all systems approaches can operate (Flood and Carson, 1993, p. 251). The concept of complementarism is a key building block in moving to development of a philosophy of systems.

This section presented a general discussion of philosophical paradigms and then considered some of the implications of such paradigms upon systems thinking. The schema introduced in this section and the ensuing discussion will contribute significantly to the next section where the concept of development of a systems philosophy will be presented.

## A SYSTEMS PHILOSOPHY

This section extends the concepts of philosophical paradigms discussed above and considers a systems philosophy to serve as a foundation for this research. However, it must be made clear from the beginning that the idea of developing one all-inclusive systems philosophy is neither feasible, nor desirable. The key to successful development of a philosophy in support of systems-based research is the concept of complementarism (also referred to as pluralism or methodological pluralism) (Jackson and Keys, 1984; Jackson, 1987, 1990, 1991, 1997, 1999; Flood and Jackson, 1991; Murthy, 2000; Mejia, 2004).

> "Complementarity is an important principle which is necessary for unravelling all dimensions of complex systems.... Most of the methods and techniques...can identify only some of these [dimensions] at a time and so tell only about some dimensions of a complex system. Thus it becomes essential to use complementarily a number of system methodologies to understand the complex system fully as far as possible" (Murthy, 2000, p. 90).

Complementarity indicates that in the application of systems-based methods, researchers must develop a clear understanding of the philosophical (epistemological and ontological) concepts that underwrite the various systems-based methodologies or approaches, and then 1) determine which approaches can be best utilized and employed in a given situation; and 2) critique the use of systems-based approaches based upon these philosophical underpinnings and the specifics of the system/problem under study.

What are the implications of this discussion on systems philosophy for the framing of research issues, the development of research plans, and the approach taken by the researcher? The implications and impacts on framing of the research issues and the development of an appropriate research design are very closely linked. The key is to develop a research concept that frames the research issues to ensure it clearly (whether implicitly or explicitly) indicates what type of systems philosophy or systems research paradigm is appropriate for addressing the research issues or answering the research questions. This may be an iterative process, as ambiguities are eliminated during review, but a significant amount of rigor must be applied to this effort, considering the foundational role issue framing has to the research. The related action, which may happen subsequently or simultaneously, is to develop a research design that is consistent with the philosophical domain of the research issues as framed, embracing the ontological and epistemological perspectives and employing a methodology that supports the appropriate paradigm.

## IMPLICATIONS OF SYSTEMS PHILOSOPHY MISALIGNMENT

For the researcher, the consequences of potential differences in systems philosophy between the stakeholders in the research are wide-ranging and could be a source of significant risk to the research initiative. Based on the four continua of assumptions discussed earlier, the number of possible combinations of assumptions and values is infinite. However, the mismatches that would hold the most risk and be the most potentially hazardous for the research are for any of the research stakeholders (e.g., researcher, reviewers, participants, etc.) to be at opposite extremes of the objectivist-subjectivist continuum. There are differences in how these philosophical differences might manifest themselves, depending on which group was at odds with the researcher. Exhibit 9 highlights potential issues and risks for some key mismatch combinations.

### Exhibit 9. Implications of Systems Philosophy Mismatches

| Philosophical Mismatch | Issues / Problems / Risks |
|---|---|
| **Researcher Objectivist-Reviewer Subjectivist** | • Lack of agreement on approach appropriate for research<br>• Proposed realist/positivist methodology not acceptable because it does not provide for construction of subjective 'reality'<br>• Reviewer disagrees that research will (can) provide "a solution"<br>• Data collection approach, based on notions of object/subject dualism (ability to observe independent of influence) and external reality, is considered invalid or irrelevant<br>• **Research not approved.** |
| **Researcher Objectivist-Participant Subjectivist** | • Participant does not recognize the value of the research, so inputs are limited<br>• Participant may intentionally or unintentionally introduce subjectivity into supposedly objective data collection<br>• Participant objects to being passively observed and is unwilling to participate<br>• **Results deemed invalid.** |
| **Researcher Subjectivist-Reviewer Objectivist** | • Lack of agreement on approach appropriate for research<br>• Nominalistic nature of proposed methodology unacceptable because it does result develop external 'reality'<br>• Reviewer disagrees with researcher position that there is not one "solution" to the system problem<br>• Subjective data collection approach is considered invalid or irrelevant by reviewer<br>• **Research not approved.** |
| **Researcher Subjectivist-Participant Objectivist** | • Participant does not contribute to construction because 'soft' problem-solving is considered invalid, 'unscientific'<br>• Participant not willing to invest resources (primarily time) needed to conduct research/analysis to level necessary to produce meaningful results<br>• Participant influences data collection / analysis efforts by trying to steer results based on input to researcher<br>• **Results of questionable value in dealing with system issues/problems.** |

In addition to ensuring alignment of the research philosophy with the research design, a major priority for the researcher has to be clearly communicating the research philosophy to research reviewers and participants to ensure the research doesn't suffer from the issues discussed in Exhibit 9. The researcher must ensure complete transparency of research intent, planning, and execution from the outset. Fully understanding the potential consequences of philosophical alignment issues, systems researchers must directly communicate to all parties where they perceive their research perspective lies along the philosophical/paradigmatic dimensions discussed earlier. At which point, research reviewers and other readers can determine whether they chose to accept the approach or not. To avoid catastrophic misalignment issues (e.g., rejection of the research), it is in the best interest of the researcher to understand the philosophical paradigm of the reviewers (especially those who approve/disapprove the research), and establish to what extent they can accommodate other philosophical perspectives. This communication needs to start as early in the concept development phase of the research as possible and continue to evolve as the research design matures, throughout the execution of the entire research effort. Communication with research participants is critical, also, but from a different perspective. While they need not understand the philosophical underpinnings of the research, it is important that they be provided at least the background of the research in order to understand their role.

This section presented a discussion of philosophical alignment (or misalignment), focusing the discussion on the negative consequences of a poor philosophical or paradigmatic alignment among stakeholders (e.g., researcher, reviewers, participants, readers, and other interested parties). Failure to consider these impacts can significantly hamper, if not completely obviate, the possibility of a successful research project. The next section discusses the background and philosophical underpinning of the grounded theory method, which is the method selected for use in this research.

## THEORY DISCOVERY AND GROUNDED THEORY METHOD

This section introduces the grounded theory method, originally conceived by Bernard Glaser and Anselm Strauss (1967), which was selected for use in conducting this research. Considering the perspective of complex system context developed in Chapter II and the discussion earlier in this chapter on philosophical paradigms, it was assessed that this research, as delineated in Chapter I, was more appropriately addressed within a more subjective, interpretivist philosophy or paradigm. This required adoption a more ideographic research methodology that provides a means of evaluating and analyzing qualitative information pertaining to the phenomenon of interest, allowing the researcher to construct a perspective or view of complex system context. The grounded theory method is one qualitative research approach that has been used in a variety of domains when researchers are attempting to build such theoretical constructs.

Developed over the course of several years of qualitative research in patient care, the grounded theory method was first articulated by Glaser and Strauss (1967) in *The Discovery of Grounded Theory.* According to its creators, this new approach provided researchers a methodology for developing theoretical constructs from a broad range of sources that were primarily qualitative in nature (including fieldwork, interviewing and documentary data), but could also include quantitative data from technical documentation or other research. One significant difference between their method and traditional research methods of the time was their assertion that the approach would (or could) result in the "discovery of theory from data" (Glaser and Strauss, 1967, 1) as opposed to what they refer to as the "overemphasis… on the verification of theory and a resultant de-emphasis on the prior step of discovering what concepts and hypotheses are relevant for the area that one wishes to research" (Glaser and Strauss, 1967, 1-2).

While often used interchangeably, it is important to make a distinction between "the grounded theory *method* and grounded theory itself. A grounded theory is the possible outcome of using the GT [grounded theory] method" (Bryant, 2002a, p. 27 – emphasis in original). The importance of this distinction is to separate the methodology from the outcome, especially considering that "there are some who claim to use the method as part of an approach that does not seek to develop grounded theories" (Bryant, 2002a, p. 27). Bryant's (2002a) point is that using the method (or claiming to do so) should not be confused with any resultant theory(ies) that emerge from the method.

While the domain within which the grounded theory method was conceived was the discipline of sociology, the originators have subsequently pointed out that the approach is appropriate in a wide range of applications. "One need not be a sociologist or subscribe to the interactionist perspective to use it. What counts are the procedures and they are not discipline bound" (Strauss and Corbin, 1990, p. 26). "Grounded theory is a general method. It can be used on any data or combination of data" (Glaser, 1999, p. 842). In the decades since first introduced, "the adoption of grounded theory [method] has gradually spread beyond its initial concentration [sociology], and... is now making inroads into other practical fields and other disciplines" (Dey, 1999, p.13). That being said, there is an ongoing debate about how broadly and in what disciplines or practices grounded theory method can and should be applied (Bryant, 2002a, 2002b; Urquhart, 2002; Dey, 1999; Goulding, 1998, 1999; Charmaz, 2000, 2002), and although the methodology has seen significant expansion in application, grounded theory method is not without criticism. These critiques of grounded theory will be discussed in a later section of this chapter.

**Philosophical Underpinnings of Grounded Theory Method**

Many discussions about the philosophical foundations of grounded theory method (Bryant, 2002a; Urquhart, 2002; Strauss and Corbin, 1990) begin by discussing the academic and research backgrounds of the method's creators. Strauss had experience working in the Chicago School of social research, and as such his bent was toward qualitative research, emphasizing the importance of fieldwork and the need for theory to be grounded in the real world. Glaser's work at Columbia University was more focused on empirical, quantitative methods and led Glaser to see "the need for a well thought out, explicitly formulated, and systematic set of procedures for both coding and testing hypotheses generated during the research process" (Strauss and Corbin, 1990, p. 25). It was through the confluence of these disparate backgrounds that grounded theory method came into being. But what were the fundamental philosophical beliefs that formed the foundation of their work?

*Grounded Theory – Ontology, Epistemology, and Paradigms*

There is a significant amount of discussion and debate on the epistemological and ontological bases for grounded theory, whether it is rooted in positivism or interpretivism/constructivism, and how tightly linked to any specific paradigm the methodology is. Based on an ontology of realism (or naïve realism), the positivistic paradigm posits that an apprehensible external reality exists. Epistemologically, positivists believe the inquirer and the object under inquiry are completely independent, and the object can be observed without influencing or being influenced by the researcher (Guba and Lincoln, 1994). The interpretivist, on the other hand, "believes that to understand this world of meaning one must interpret it. The inquirer must elucidate the process of meaning construction and clarify what and how meanings are embodied in the language and actions of social actors" (Schwandt, 1994, p. 118). This interpretivist/constructivist paradigm is based in a relativist or nominalist ontology, which supports that reality is only apprehensible "in the form of multiple, intangible mental constructions, socially and experientially based, local and specific in nature… and depended for their form and content on the individual persons or groups holding the constructions" (Guba and Lincoln, 1994, p. 110). Given the philosophical range as discussed earlier in this chapter, the question is whether an objectivist/positivist paradigm or subjectivist/interpretivist paradigm forms the philosophical basis for grounded theory method.

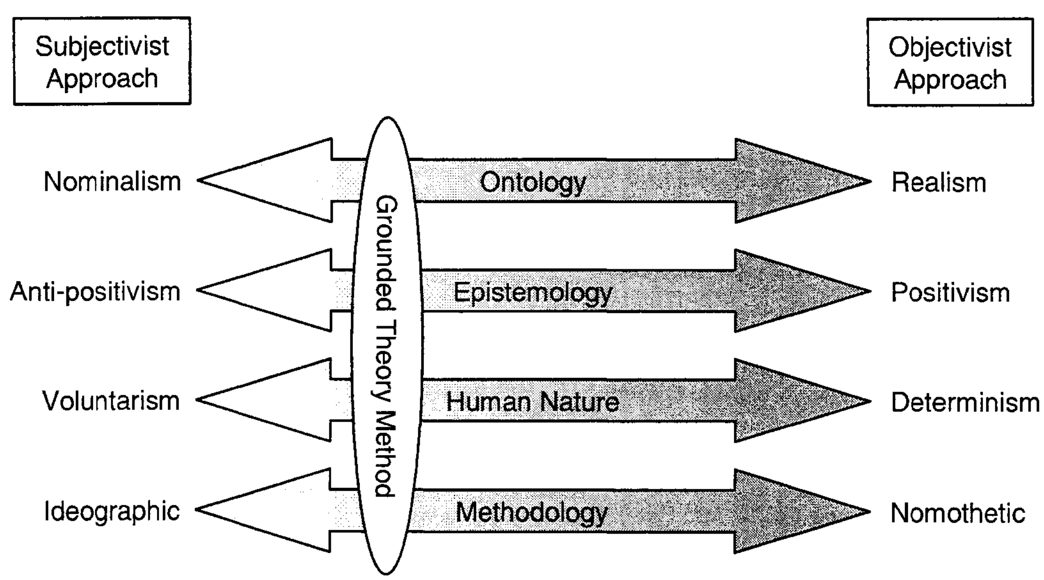
The grounded theory method "is paradoxical and unique – a method for analyzing qualitative data which also claims to be a systematic way of generating theory. For this reason alone, there are bound to be debates about whether it is positivist or interpretivist" (Urquhart, 2002, p. 45). Some (Bryant, 2002a, 2002b; Charmaz, 2000) suggest that grounded theory method is based in a positivist paradigm. Grounded theory method, as presented initially and subsequently by its creators, "demonstrates a consistently positivist strand… from the 1960s to the present" (Bryant, 2002a, p. 31). Glaser and Strauss repeatedly insist that grounded theories are grounded in the data, which Bryant (2002a) asserts implies that the researcher is simply observing a reality and from it deriving a theory – indicative of a realist ontology and positivist epistemology. Others (Goulding, 1998, 1999; Urquhart, 2002) believe the misconception that grounded theory method has a positivist basis stems from the fact that grounded theory method uses terminology, "open coding, axial coding, verification procedures and so forth, which has connotations of positivist practices" (Goulding, 1998, p. 51). The key to understanding the originator's choice of terminology can be found in the dominance of the positivistic paradigm within the research environment at timeframe during which the concept of grounded theory method was first presented, which prompted them to present their concept in positivistic terms (Urquhart, 2002). This running debate presents an impasse for the researcher trying to ascertain the philosophical roots of the grounded theory method. But, what are the roots of this disagreement?

Much of the lack of consensus on the epistemological and ontological underpinnings of the grounded theory method stems from the ambivalence and changing perspectives of Glaser and Strauss themselves (Dey, 1999). Over the years, Glaser has maintained that theory is directly drawn from data – pointing toward a positivistic basis, which is in line with the nomothetic end of the methodological axis of the subjective-objective dimension. On the other hand, Strauss (in collaboration with Corbin) has indicated a much more interpretivist perspective on what is knowable and how it can be derived – indicating a nominalist ontology and anti-positivist epistemology. This perspective, which assumes that a researcher must gain a deep and rich understanding of the experiences of those who live in the environment in question in order to understand that phenomenon, is also strongly aligned with the ideographic methodological position. This dichotomy creates a philosophical dilemma for researchers considering using grounded theory method in any application, because for researchers to claim they are conducting credible research, they must be able to clearly articulate the fundamental philosophical assumptions (Urquhart, 2002) of their work and explain why the method chosen is appropriate to their research goals. They must also understand if the methodology they chose (grounded theory method or otherwise) carries with it some philosophical baggage.

Returning to the 'Subjective-Objective Dimension' presented earlier in this Chapter, the final axis, Human Nature, has to be considered. With regard to Human Nature, the literature on grounded theory method is again split, with those supporting the positivist paradigm (Bryant, 2002a, 2002b; Charmaz, 2000) indicating that the interaction between individuals (researchers or actors) and their environment is limited, with the environment simply being there for observation – which suggests a deterministic perspective. While the interpretivist camp (Goulding, 1998, 1999; Urquhart, 2002), on the other hand, has a more voluntaristic view, submitting that individuals are actively involved in interacting with and influencing the situation in which they find themselves.

The best way to bring closure to this discussion on the philosophical foundation of grounded theory method is with a description of the general intent of grounded theory method as presented by Glaser and Strauss in their original work. "The primary endeavour is to describe, interpret, and analyse the social world from the participant's perspective, and that all rigid a priori researcher imposed formulations of structure, function, purpose and attribution are resisted" (Glaser and Strauss, 1967 cited in Orlikowski and Baroudi, 1991, p. 17). This indicates that while there may be positivistic elements within the overall methodology, proper use of grounded theory methods suggests the researcher must be able to understand various perspectives and to be able to construct reality through interpretation of those perceptions. Exhibit 10 below depicts this philosophical perspective of the grounded theory method with reference to Burrell and Morgan's (1979) Subjective-Objective Dimension.

**Exhibit 10. Grounded Theory Method and the Subjective-Objective Dimension**



**Rationale for Selection of Grounded Theory Method**

Recall the statement by Glaser that "Grounded theory is a general method. It can be used on any data or combination of data" (Glaser, 1999, p. 842). That said, there are certain types of research issues or questions for which grounded theory is an appropriate approach and others for which it is not. Grounded theory method is applicable in addressing questions that require engaging with 'actors-in-contexts' and where "the process of research might not be one of discovering or establishing truths, but rather concerned with developing understanding and adequate models for specified purposes" (Bryant, 2002a, p. 35). The key is that "we can adopt grounded theory strategies without embracing the positivist leanings of earlier proponents of grounded theory" (Charmaz, 2000, p. 510). The strength of grounded theory method can most effectively be brought to bear where it is desired for the resulting theoretical concepts or constructs to be "understandable and enlightening to individuals who have some familiarity with the social phenomena under investigation, either as participants or as lay observers" (Turner, 1983, p. 347) and where the quality of the results of the research is "more directly dependent upon the quality of the research worker's understanding of the phenomena under observation" (Turner, 1983, p. 335). The level of richness referred to here is what this research called for. Addressing the research questions presented in Chapter I required engaging with individuals who understood the phenomenon referred to as complex system context.

According to Wilson and Hutchinson (1996), Dey (1999) and Bryant (2002a), many misapplications of grounded theory method have resulted from researchers trying to superficially apply the tools of grounded theory method, without fully incorporating the interpretive aspects of the grounded theory approach that require the development of abstract theoretical concepts. Therefore, grounded theory method is not appropriate for research questions that are looking for a way to conduct limited coding and analysis of a qualitative data set or simply quantify qualitative data. This was an important aspect to consider in selecting a research methodology for this research. Given that this research was looking for a richer discovery process with the intent being theoretical construction, grounded theory method was considered a viable candidate.

The grounded theory method is called for in cases where the goal is to either "uncover and understand what lies behind any phenomenon about which little is yet known…[or] gain novel and fresh slants on things about which quite a bit is already known" (Strauss and Corbin, 1990, p. 19). With regard to this research effort, while much is said in systems literature about system context, there remains a lack of understanding of system context as a phenomenon and there remains significant ambiguity about the concept of context. This suggests a new and deeper look at the concept is called for, making grounded theory method particularly appropriate for this research.

Grounded theory methods are also effective for use in cases where building theory or developing "theoretically informed interpretations" is the goal (Strauss and Corbin, 1990, p. 22). Building theory "implies interpreting data, for data must be conceptualized and concepts related to form a… theoretical formulation" (Strauss and Corbin, 1990, p. 22). As articulated in the preceding chapters (problem statement, research questions, research setting), this research clearly required the researcher to construct an understanding of the concepts associated with the phenomena of complex system context in order to enable the researcher to develop a framework that was applicable and understandable to systems professionals and practitioners and would help them gain a greater understanding of context. To accomplish this, the researcher had to become intimately familiar with how systems context is perceived and how the concept is used as part of systems-based efforts. This focus on the interpretation of the phenomena and the construct of concepts made this research project an appropriate instance for the use of the grounded theory method.

The grounded theory method was selected as the method of choice for this research because the degree of alignment among the grounded theory approach, the research purpose, and the researcher was compelling. As indicated above, the problem being investigated in this research clearly called for the researcher to gain a deep understanding of the concept of complex system and required a methodology that provided appropriate rigor to analysis of such information. Similarly, as discussed in the preface, the researcher's philosophical perspective was in line with taking a qualitative view of the phenomenon of complex system context. So, researcher, research, and method were determined to be very strongly aligned philosophically toward the subjective end of the philosophical spectrum – with a nominalist ontology, an anti-positivist epistemology, a voluntaristic view of human nature, and an ideographic concept of methodology.

## GROUNDED THEORY RESEARCH DESIGN CONCERNS

This section presents some of the concerns found in the literature on grounded theory method by first discussing several criticisms and then submitting ways in which any potential impacts can be mitigated. When they introduced the grounded theory method, Glaser and Strauss (1967) made a comparison between grounded theory and what they term 'logico-deductive' based theory to assess two approaches to theory and their "relative merits in ability to fit and work (predict, explain, and be relevant)." They make the assertion that "the adequacy of a theory… cannot be divorced from the process by which it is generated" (Glaser and Strauss, 1967, p. 5). Their point being that the credibility or merit of a grounded theory is based on the fact that it is inductively derived from and directly tied to the data, through a transparent, well-documented analytical approach. Glaser and Strauss (1967) submit that much of the discrediting of grounded theory comes from those who base their assessment of credibility and validity on "the canons of rigorous quantitative verification… sampling, coding, reliability, validity, indicators, frequency distributions, conceptual formulation, hypothesis construction, and presentation of evidence" (Glaser and Strauss, 1967, p. 224). According to Goulding (1998), researchers employing grounded theory method "do not follow the traditional quantitative canons of verification. They do, however, check the development of ideas with further specific observations, make systematic comparisons and often take the research beyond the initial confines of one topic or setting" (Goulding, 1998, p. 55).

The question of the quality or goodness of research is one that must also be addressed. The quantitative perspective of the canons of science, discussed above, has established the benchmarks of rigorous research as "internal validity (isomorphism of findings with reality), external validity (generalizability), reliability (in the sense of stability), and objectivity (distanced and neutral observer)" (Guba and Lincoln, 1994, p.

114). Contrarily, qualitative researchers have identified a different set of criteria for assessing attainment of the goals of the canons of rigorous research. In qualitative research, the criteria most frequently used are credibility (associated with accuracy and transparency), transferability (applicability of findings in other contexts), dependability (able to account for changes), and confirmability (requires connection of findings to data, accountability) (Lincoln and Guba, 1985; Guba and Lincoln, 1994). According to the Glaser and Strauss (1967), these qualitative criteria are the standards researchers using their method should seek to meet in order to establish that their research has been sufficiently rigorous. While they submit that their method can fulfill these requirements, there are some who do not believe it does.

**Criticisms of Grounded Theory Methods**

Over the years since its inception, the use of grounded theory methods has increased significantly. "The adoption of grounded theory has gradually spread beyond its initial concentration [area], and... is now making inroads into other practical fields and other disciplines" (Dey, 1999, p. 13). However the research approach is not without its problems. From the beginning, grounded theory was polemical, primarily because its originators were essentially attacking the firmly established and widely accepted 'logico-deductive' approach to theory generation and testing, which was in use within the scientific and research fields (Glaser and Strauss, 1967, p. 5). Desiring to gain acceptance from the quantitative methodologists among their peers, the method's founders "used the language of positivism: variables, hypotheses, properties, theoretical sampling, theoretical ordering, and so on. It is often this discourse that cause the frustration for the qualitative researcher" (Keddy et al, 1996, 450). However, grounded theory method has been the target of a many other criticisms above and beyond this refuting of accepted quantitative, positivistic approaches or the debate over its philosophical foundations presented earlier.

*Identity Crisis*

One of the most ubiquitous criticism of grounded theory can be characterized as an identity crisis, and is based on the wide chasm (both philosophical and methodological) that has developed between the method's original architects, Glaser and Strauss, as a result of their taking divergent paths in the further development of grounded theory. Over the years, the method's creators have adopted significantly different perspectives in evolving their original concepts, with their debate over these differences even becoming heated at times. When Strauss (collaborating with Corbin) released his 1990 rendition of the methodology, Glaser's critique was scathing and pejorative, stating that Strauss's new work certainly contained a methodology, but not grounded theory and that it disregarded the vast majority of concepts from the original 1967 text (Goulding, 1998). Glaser also expressed concerns that the positivistic undertones, rigid coding rules, and highly-structured approach put forward by Strauss and Corbin (1990) led to a misconception that grounded theory was attempting to use qualitative research to quantify findings (Dey, 1999). Strauss and Corbin (1990, 1998) have also been criticized for imposing theories on the data "rather than letting theory emerge through the analysis" (Dey, 1999, p. 14).

According to Charmaz (2002),

> "Grounded theory methods have taken two somewhat different forms since their creation: constructivist and objectivist. The constructivist approach places priority on the phenomena of study and sees both data and analysis as created from the shared experience of the researcher and participants... Objectivist grounded theory, in contrast, emphasizes the viewing of data as real in and of themselves. This position assumes that data represents objective facts about a knowable world" (Charmaz, 2002, p. 677).

Needless to say, for those looking to employ grounded theory as a research approach, this dissention and vociferous disagreement between the founders of the methods caused (and still causes) a great deal of angst. The fact that the originators of the grounded theory method have been unable to reach consensus about what it is or how it should evolve casts aspersions on the method's credibility.

*Grounded Theory Method and Verification*

Another source of criticism, which has been further fueled by differing perspectives of the originators, is the determination of the role of verification in grounded theory. Glaser's position has been that "the task of grounded theory is to generate hypotheses, not test them" and "verification is irrelevant precisely because ideas are induced from the data" (Dey, 1999, p. 20). Contrary to this, Strauss and Corbin submit that verification is an inherent part of the grounded theory approach. "...there is built into this style of extensive interrelated data collection and theoretical analysis an explicit mandate to strive toward *verification* of its resulting hypotheses... This is done *throughout the course* of the research project, rather than assuming that verification is possible only through follow-up quantitative research" (Strauss and Corbin, 1994, p. 274 – emphasis in original). This bifurcation over whether verification is legitimately part of the grounded theory method is another source of consternation for grounded theory researchers and critics alike.

*Deviations from Original Methodology*

Some critics of grounded theory methods point out that many researchers have deviated from the original methodology as intended and developed, committing numerous philosophical and methodological errors, and thereby damaging the credibility of the method. Part of this is due to a dilution of grounded theory method's basic canons of inquiry as originally spelled out by Glaser and Strauss. The rapid diffusion of the approach across a wide range of disciplines and areas of practice has resulted, some believe, in researchers employing a handed-down, watered-down version of grounded theory method (Wilson and Hutchinson, 1996; Bryant, 2002a; Urquhart, 2002). Many studies reference grounded theory method, but fail to implement or employ major portions of the methodology (Bryant, 2002a). "At best this amounts to a selective rewriting of GTM [grounded theory method]; and at worst, mention of GTM is a way of masking 'an anything goes approach' that is methodologically arbitrary and ultimately indefensible" (Bryant, 2002a, p. 32).

According to Dey (1999), these deviations are partially attributable to Strauss and Corbin's 1990 text, Basics of Qualitative Research: Grounded Theory Procedures and Techniques, which has become "the standard introduction to grounded theory in place of the original text" (Dey, 1999, p. 13). Based on this work, Strauss is accused of not understanding "the basic tenets of his own approach...[introducing a]...new coding paradigm involving conditions, context, action/interactional strategies, and consequences...[which] seems to impose a conceptual framework in advance of data analysis, it does not seem to sit easily with the inductive emphasis of grounded theory" (Dey, 1999, p. 13-14). Another source of deviation is the establishment of rigid guidelines or rules for judging the value or acceptability of grounded theories by those teaching the use of grounded theory methods and overseeing its use in research (Wilson and Hutchinson, 1996; Dey, 1999). For example "methodological rules such as minimum sample sizes or diagrammatic presentations of theory" (Dey, 1999, p. 14) have been made taught as part of the methodology, which goes against the original intent of grounded theory to move away from the guidelines for research rigor imposed by more positivistic methods. Another example of methodological deviations is the erroneous application of quantitative/positivistic canons of rigor to grounded theory. "The outcome is a study replete with conventional positivistic terminology, including random sampling, reliability and validity statistics, independent and dependent variables and the like" (Wilson and Hutchinson, 1996, p. 124).

*Premature Closure*

Another shortcoming of grounded theory method, as practiced, is referred to as premature closure (Wilson and Hutchinson, 1996; Dey, 1999). This is referring to a researcher's failure to go beyond a superficial analysis of the data, never developing the abstract concepts that are needed to form the foundation for grounded theory development. "Some researchers fail to transcend an initial 'in vivo' coding and so fail to move beyond the face value of their data" (Dey, 1999, p. 14). Similarly, Benoliel (1996) posits that many who claim to be using a grounded theory approach are not, because grounded theory should “explain how social circumstances could account for behaviors and interactions of the people being studied” (Benoliel, 1996, p. 413) but in application, many researchers never get beyond focusing on experiences as lived by the subject. This has resulted in concern over the failure of some grounded theorist to “analyze data fully and especially to develop more abstract ‘conceptual and theoretical codes’... as the building blocks of theory” (Dey, 1999, p. 14). This lack of conceptual depth is also partially attributable to the failure of researchers to explicitly account for their coding and sampling decision, and conceptual constructions, which results in a lack of the necessary analytical transparency (Bryant, 2002a). This is a legitimate concern – when research is called grounded theory when it only shallowly delves into the data and fails to draw out the richness of the actions of the actors and their interrelationships.

*Adoption of Preconceived Concepts*

The issue of previously established conceptualizations or existing theories unduly influencing the derivation of theoretical constructs in employing grounded theory methods is a major area of critical contention. The concept of theoretical sensitivity, discussed in the original text, and elaborated upon in subsequent writings, seems to be the primary source of confusion. Theoretical sensitivity implies that researchers should enter the research “with as few predetermined views as possible, especially logically deducted, prior hypotheses.... The ‘tabula rasa’ idea remains a popular misconception about GTM [grounded theory method]...[however] there is nothing in the GTM literature that specifically precludes looking at relevant literature before entering the field" (Urquhart, 2002, p. 49-50). The basic concern is the degree to which researchers are expected to approach the research with a blank slate or 'tabula rasa,' and the extent to which grounded theory method allows for awareness of existing theories and technical literature. While it is reasonable to expect that the findings of the grounded theorist not be overly swayed by external influences, it is not reasonable to expect that a researcher enter the field with no prior knowledge of the domain within which he is conducting research.

**Addressing the Criticisms of Grounded Theory**

It would seem that the issues presented above make grounded theory method virtually irrecoverable as a research approach, or as asked by Bryant (2002a), "Given the foregoing discussion, why not simply jettison GTM in its entirety?" (Bryant, 2002a, p. 34). The answer to this question is simply that the strengths of the methodology far outweigh its shortcomings, and if handled properly and taken into account during the research design, most of the potential problems raised in the criticism of the approach can be significantly mitigated if not completely avoided. While some (Bryant, 2002a, 2002b; Dey, 1999) seem only interested in recovering the research methods and techniques put forth in the grounded theory literature, others (Urquhart, 2002; Goulding, 1998, 1999) believe the fundamental underpinnings of grounded theory are sound, making the entire grounded theory approach worth retaining.

The issue at hand is how a researcher can develop a grounded theory research design that will limit the impacts of grounded theory method's weaknesses. Bryant (2002a) presents one of the best descriptions of what differentiates a well-done grounded theory research work from one that fails to adequately compensate for the method's shortcomings. Referring to Orlikowski's (1993) research on organizational change and implementation of CASE tools, he states, "What distinguishes the paper…is its extensive detail, and the ways in which the differing accounts...illustrate general and specific aspects of the respective experiences.... One aspect of Orlikowski's paper is the way in which she 'grounds' her own use of grounded theory method" (Bryant, 2002a, p. 34). He goes on to point out how Orlikowski explicitly detailed how grounded theory method offers, "a distinctive and important basis for research… in particular to anything focused on people's actions and interpretations in organizational and other social contexts" (Bryant, 2002a, p. 35). It is Orlikowski's extensive detail and explicit transparency that make it a strong grounded theory study.

One paradox of grounded theory method is that it is referred to as being inductive and emergent, and at the same time systematic. The grounded theory method is a combination of creativity and interpretation with some guidelines in place to help enhance that creativity (Urquhart, 2002). In reference to the emergence of theory from data,

> "Most researchers who have used grounded theory method will attest to that 'emergence' – not necessarily a mystical process, but one where one sees the data in an entirely new way. Putting aside preconceptions does result in original insights to the data, and the method of constant comparison does enable the researcher to understand their data set and 'ground' the theory" (Urquhart, 2002, p. 50).

With regard to how systematic grounded theory method is, Urquhart (2002) stresses the importance of the philosophical perspective of the researcher. She references a study in which the same data was analyzed by different researchers using grounded theory method. "Unsurprisingly, the analytic categories generated by the two researchers *are* different." However the study indicated that the subjectivity of the resulting analysis was related to the philosophical position of the researcher. So she concluded that how systematic the method is "may be entirely in the eye of the beholder" (Urquhart, 2002, p. 50). The most effective way to minimize impact of this confusion when developing a grounded theory research design is by being totally transparent in the research approach and clearly delineating the intended outcome of the research.

Considering the concern expressed above regarding avoiding preconceptions, in those cases where grounded theory is being used in an area where existing theory and research are relatively sparse, avoiding the influence of extant theory is not a major concern and is relatively easy. However, in cases where a theoretical foundation already exists, to avoid allowing it to color the conceptions of the researcher, "the recommendation is that during the early stages of the study the researcher should avoid steeping him/herself too heavily in the findings of others.... However, this does not mean that all literature is abandoned during the formative stages" (Goulding, 1999, p. 868). The key point in this statement is 'too heavily.' This means that the researcher must gain a broad understanding of the existing theory and literature to develop theoretical sensitivity, but should not delve into details of specific research or theories related to the research at hand.

The implications of these observations are straightforward. They imply that a sound grounded theory research design must include a stipulation for inclusion of steps to be taken to ensure the maximum possible degree of transparency of all decisions, conceptualizations, coding, comparison, etc. through extensive documentation and use of methods such as member checking and peer reviews. The design must ensure a painstaking process for auditing and tracking all of this detail, which suggests the use of one of the available computer-based tools for qualitative research. Additionally, it requires that the research design emphasize the importance of the constant comparative method and include provisions for continued review of assumptions and developing conceptualizations throughout the entire research process. Lastly, it is critical for the research design to clearly delineate the philosophical paradigm within which the researcher intends to apply the grounded theory approach, in order to address questions of subjectivity.

**CHAPTER SUMMARY**

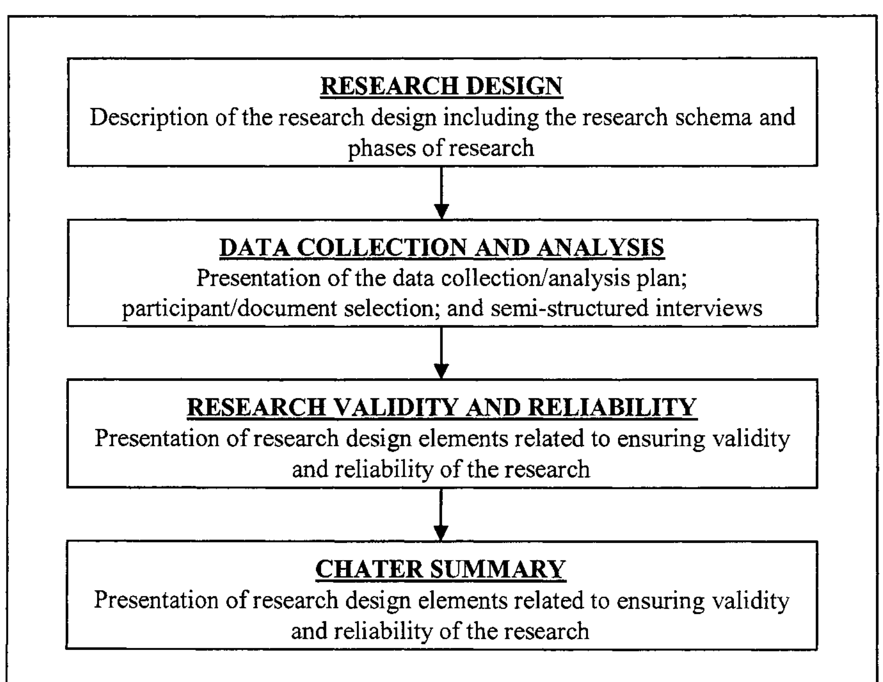
This chapter started this presentation of the overarching perspective for this research with the introduction of a general schema for the description and articulation of philosophical paradigms. While this schema was not specific to this research, a connection was made to it through the development of a systems philosophy and a discussion of the potential implications of a misalignment of systems philosophy. Theory discovery and the grounded theory method were then presented, providing a discussion of the philosophical underpinnings of the method and its background. The final section of the chapter brought to light some of the concerns raised regarding the grounded theory method and submitted how proper research design can mitigate some of the risks of these concerns. With this chapter's discussion of philosophy and the grounded theory method as a foundation, Chapter IV describes the research design developed for this research and then discusses how the design was executed in carrying out the research.

# CHAPTER IV

# RESEARCH METHODOLOGY

This chapter on the research methodology presents an overview of the research design, and the phases of the research. It then describes how the research was executed, walking step by step through the phases of the research as conducted. It provides a bridge between the conceptual/philosophical discussion presented in Chapters II and III, which reported the state of the systems body of knowledge and discussed the philosophical underpinnings of the research; and the actual conduct of the research, with resultant developments and conclusions, which are presented in this chapter and Chapters V and VI. Exhibit 11 provides a graphic representation of the flow of information presented in Chapter IV.

**Exhibit 11. Chapter IV Layout Diagram**



The intent of discussing the research methodology is to demonstrate that the actions taken in carrying out the plan did in fact support and address the research questions identified in Chapter I:

1. What are the constituent elements of complex system context, and what attributes and dimensions characterize these elements?
2. What systems-based framework can be developed for constructing and articulating complex system context?

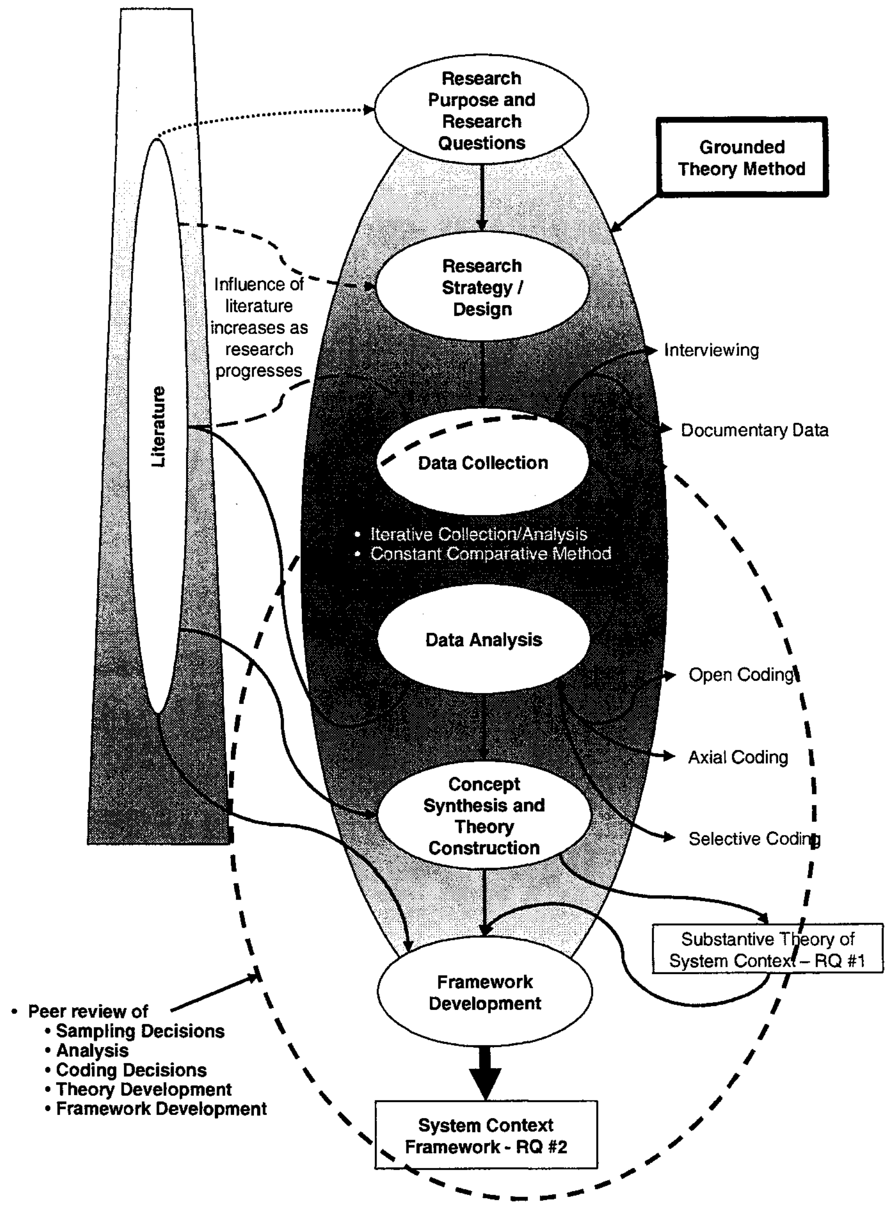
The end result of this research effort is both the development of a grounded theoretical construct for complex systems context and the design of a framework for establishing system context within the domain of complex systems problems.

## RESEARCH DESIGN

This section lays out the details of the research design and the approach taken in executing the research plan, including the phases of the research, the selection of participants and other data sources, and the strategies used in data collection and analysis. Finally, a number of concerns related to validation and reliability are presented along with a discussion of actions taken to address or mitigate those concerns.

Exhibit 12 presents a diagram of the overall research plan. Beginning with the formulation of the research purpose and research questions, the plan moves through development of research strategy and design, data collection, data analysis, concept synthesis and theory construction, and framework development. One key aspect of the research plan was the role or influence of scholarly and professional literature. In using the grounded theory method, researchers are cautioned against allowing a significant

**Exhibit 12. Research Design Schema**




influence of existing literature early in the research, where it might tend to produce preconceived notions about the phenomenon being studied. In the early stages of this study, a general familiarity with systems-related literature was necessary to properly frame the research; however, as discussed in Chapter III and in keeping with the tenets of ground theory method, the researcher was careful not to allow extant literature and theory to unduly influence the direction of the study. This was accomplished through a twofold process. First, as pointed out in Chapter II, within the existing body of knowledge on complex systems, there was a dearth of theoretical concepts or research, so the opportunity for influence in the specific topic area of this research was relatively low. Second, the domain familiarization undertaken in the early phases of the research was at a very general systems theory level, avoiding the risk of undue influence on the research. As the research progressed through the grounded theory method and the theoretical construct began to emerge, additional reflection and comparison with the existing systems body of knowledge was permitted, essentially using this knowledge as another source of data (Goulding, 1999). In the diagram, this incremental increase in influence is represented by the widening and darkening of the literature wedge next to the flow diagram.

The shading of the vertical ellipse in Exhibit 12 illustrates that while the grounded theory method was the underpinning of all aspects of the research, during the development of the research purpose and research questions, and during framework development the influence was more indirect or tangential. The two-headed arrows connecting data collection with interviewing and documentary data indicate that the researcher reengaged with data sources as the need arose (e.g., for clarification, additional selective sampling, member checking, etc.).

The cyclical process shown between data collection and data analysis represents the iterative nature of this part of the research, following the constant comparative method concept of grounded theory. As the data was analyzed and categories and concepts emerged, the research continually went back to the data to ensure the developing theoretical constructs were properly supported or grounded. The three phases of coding (open coding, axial coding, and selective coding) are connected with data analysis with double-headed arrows to represent that the coding processes are another iterative element of the grounded theory method. The dashed ellipse extending from data collection through framework development represents the efforts to increase reliability and validity in the study by including multiple reviews of the research process and outcomes throughout the research.

While this representation of the research shows a linear progression through the study, it is also beneficial to look at the research from the perspective of the research questions. In doing so, the research can logically be broken down into two phases: the Theory Development Phase in response to research question 1:

1. What are the constituent elements of complex system context, and what attributes and dimensions characterize these elements?

and the Framework Development Phase in response to research question 2:

2. What systems-based framework can be developed for constructing and articulating complex system context?

Having introduced the overall design of the research, the next section will present a brief discussion of these two phases of the research.

**Phases of Research**

The two phases of the research, theory development and framework development, are shown in Exhibit 13. This table illustrates methods and primary references for data collection and analysis within each phase, showing that the grounded theory method formed the foundation for the research design. The two phases were distinguished as separate and distinct because of the differences in the activities involved, methods used, and, most importantly, the outputs/outcomes resulting from each, which will be discussed in detail in the following sections, which describe these two phases of the research.

**Exhibit 13. Phases of Research**

| *Research Phase* | *Data Collection Methods* | *Data Collection Reference* | *Data Analysis Methods* | *Data Analysis Reference* |
|---|---|---|---|---|
| **Theory Development** | Grounded Theory - Semi-Structured Interviews; Documentation Review | Glaser and Strauss, 1967; Strauss and Corbin, 1990; Charmaz, 2002 Patton, 1987 | Grounded Theory | Glaser and Strauss, 1967; Strauss and Corbin, 1990, 1998 |
| **Framework Development** | Grounded Theory | Glaser and Strauss, 1967; Strauss and Corbin, 1990 | Grounded Theory | Strauss and Corbin, 1990, 1998 |

**Theory Development Phase**

The primary outcome of the theory development phase was a grounded theory of complex system context in response to research question 1 – 'What are the constituent elements of complex system context, and what attributes and dimensions characterize these elements?' In referring to this phase as theory development, the researcher considered the concept of theory as a "continuum rather than a dichotomy" Weick (1995, p. 386). From this perspective, most things called theories are actually just approximations of theory, and things such as "general orientations… broad frameworks… analysis of concepts… post-factum interpretation… [and] empirical generalization" are all parts of the development of theory (Weick, 1995, p. 385). Weick's view of theoretical concepts suggests that researchers not reserve the term 'theory' for referring only to the ultimate product of general theory development; but rather, they should also refer to the interim steps of the process as theory (Weick, 1995). When operating under this theorizing approach, at some intermediate position along the continuum of theory development, it is paramount for researchers to articulate their purpose and perspectives with absolute clarity. In the case of this research, the theoretical construction that was developed falls at some point on the continuum toward a general theory, but should not be considered the ultimate theoretical product. The actual resultant theory and where it sits along this continuum will be discussed further in Chapter V.

In the initial phase of the study the grounded theory method was applied to qualitative data to develop the theoretical construct for the concept of complex systems context. Recalling from the discussion of the grounded theory method in Chapter III, the grounded theory method is used

> "...to develop an inductively derived grounded theory about a phenomenon. The research findings constitute a theoretical formulation of the reality under investigation, rather than consisting of a set of numbers, or a group of loosely related themes. Through this methodology, the concepts and relationships among them are not only generated but they are also provisionally tested" (Strauss and Corbin, 1990, p. 24).

In keeping with the tenets of grounded theory method, especially the concept of constant comparative method, the key elements of the theory development phase, interviewing and documentation/literature review, occurred simultaneously throughout that phase of the study.

As discussed in Chapter III and earlier in this chapter, researchers must strive to avoid any preconceived ideas about their area of research. This notion must be balanced with the requirement for researchers to develop theoretical sensitivity, which calls for a clear understanding of the domain within which the phenomenon they are studying exists, while avoiding theoretical preconceptions. In order not to unduly constrain the emergence of grounded theory, the researcher specifically did not establish or adopt an a priori definition of complex system context. However, to proceed with the research effort, it was necessary to establish from literature how (or where) to initially focus on the concept of system context in order to begin data collection. Chapter II presented a characterization of complex system context, which served as the initial starting point. As the theoretical construct of complex system context emerged, the concept was refocused to remain grounded in the data and consistent with the findings of the research.

**Framework Development Phase**

The primary outcome of the theory development phase was a grounded theory of complex system context, which then served as the primary foundation for responding to research question 2 – 'What systems-based framework can be developed for constructing and articulating complex system context?' As used in this research, the term framework refers to a conceptual model or paradigm that can be applied to carry out some specific function or task. The Complex System Contextual Framework (CSCF) developed through this research not only provides the conceptual basis for constructing complex system context, but also supports the future development of methodologies that can be used by a systems practitioner to articulate complex system context in a form that can be readily applied within complex system problem analysis.

The CSCF was constructed as the grounded theory of complex system context was articulated during the theory development phase. While the final CSCF was not created until theory development was complete, there was iteration between the two phases as the theory began to emerge. The strength of the framework is derived from its being firmly based in the grounded theoretical construct of complex system context. Through the theory, the elements of complex system context and their interrelationships were identified and the associated attributes and dimensions were characterized. These items served as the building blocks of the CSCF, a natural extension of the grounded theory effort. The resultant framework answers the research question by providing an excellent way of conceptualizing and capturing the context of a given complex system. Chapter V introduces the CSCF and Chapter VI discusses the framework's implications and potential for future development.

## DATA COLLECTION AND ANALYSIS

This section presents the strategy that was developed for the collection and analysis of data. The discussion begins by addressing the criteria by which participants and documentation were selected for inclusion in the study. A synopsis of the steps through which data is collected and analyzed is then presented to show how the grounded theory method leads to the construction of a theory (grounded in the data) about the phenomenon under study.

In applying the grounded theory method in this research, data collection and analysis occurred concurrently and in a repeated cyclical fashion, and they also had a significant influence on each other. As data were collected and analyzed the emerging, developing concepts shaped and directed the following data collection efforts. As the concepts were further refined and synthesized, the collection focused narrowed on targeting specific areas where additional depth or understanding was needed.

**Participant and Documentation Selection**

The primary sources of data for this research effort consisted of semi-structured interviews. To a lesser degree, documentation (reports, monographs of past systems engineering / analysis efforts) was also included as a data source. Participants in the semi-structured interviews were solicited from individuals representing a combination of public and private organizations. There were two categories of individuals considered relevant to this research: those who conduct systems analysis/systems engineering or apply other systems-based approaches to addressing complex system problems, and those who are (or have been) associated with the conduct of research or teaching of systems-based approaches as part of a higher level academic institution. The criteria used for selection of participants for one-on-one interviews required they have 'significant education and/or experience' in the analysis of complex systems and complex system problems. These criteria were specifically defined as follows:

- **Significant education**: a graduate-level degree (Masters or higher) in a curriculum relevant to systems-based approaches (e.g., systems analysis, systems engineering, operations research, engineering management, industrial engineering)
- **Significant experience**: three or more years of work (individually or as part of a team) on initiatives involving the analysis of a complex system

or complex system problem of the scope and magnitude of those referred to in Chapter II.

The sampling strategy implemented the concept of maximum variation sampling as discussed in the Limitations section of Chapter I. Several items were selected as key characteristics for constructing the sample, and then selection was carried out to ensure variation of these key characteristics. The characteristics selected for variation in this research were the primary selection category (education and experience criteria), and the actual domain within which systems experience or research had been done. The selection was designed to achieve maximum variation among academic versus practitioner, public versus private sector, and defense-related versus other domains. The selection accounted for the domain within which each participant had gained their experience, with the goal being to maximize the variation in order to later extend or generalize the resulting theory to a wider domain, thereby increasing generalizability of the resultant theory. Each participant's experience was evaluated and categorized, and listed on a matrix, which will be presented and discussed further in Chapter V. Each respondent was asked to identify other individuals with the appropriate background for potential interviewing. This provided the researcher with a wider pool of potential candidates from which to select participants. The interviewing strategy also included the use of asynchronous computer-based methods (email) for interview follow-up and additional data collection from the interview candidates.

The documentary data collection included documents from organizations involved in the analysis of a complex system or complex system problem of the scope and magnitude discussed in Chapter II. The data included reports of major systems engineering or analysis efforts and documents that described the process employed for such efforts. Only documents published in academic sources, formal reports, and organizational policies and procedures were accepted for this portion of the data collection.

This section provided an overview of the selection strategy employed in carrying out the data collection for the research. With this overview of the data collection approach, the following section will discuss, in greater detail, the semi-structured interviews.

**Overview of Semi-Structured Interviews**

As discussed earlier, the primary source for the qualitative data used in this research was a series of semi-structured interviews. Following the grounded theory method, data collection and analysis were conducted in parallel using the constant comparative method, continually going back to the data to ensure that as categories and concepts emerged the developing theoretical constructs were properly supported or grounded in the data. The method for conducting the semi-structured interviews followed one of the models presented in Patton's (1987) discussion of depth interviewing, with the options being "(1) the informal conversational interview, (2) the general interview guide approach, and (3) the standardized open-ended interview" (Patton, 1987, p. 109). The standardized open-ended interview approach was not chosen due to concern that standard questions might overly constrain the dialog across a range of respondents, and also due to the emphasis within the grounded theory method for ensuring the researcher's conceptions don't overshadow those of the respondent.

The informal conversational interview was not chosen, because of concern that the lack of structure might make it challenging to keep the interviews on topic and therefore impose an unreasonable time burden on the participants in order to ensure required data was obtained. The option chosen was the use of an interview guide, because this approach "...keeps the interaction focused, but allows individual perspectives and experiences to emerge" (Patton, 1987, p. 111).

An interview guide was developed based on the preliminary literature review which identified the gaps to be addressed in the research, focusing on ease of use and functionality. An example of the guide is presented in Appendix A. Once the guide was finalized, individual one-on-one, face-to-face interviews were conducted with each of the participants. Interviews were recorded and transcribed, and the transcriptions were provided to each respondent for them to verify the accuracy of content and ensure that it correctly reflected their conversation (member checking as discussed in Chapter III). Specifics of the actual interviews conducted are presented in Chapter V.

**Data Analysis**

The NUD*IST software package (Non-numerical Unstructured Data * Indexing Searching and Theorizing, Version 6 by QSR - hereafter referred to as N6) was used to document and track the data collection and analysis processes. N6 is specifically designed to aid researchers handling unstructured qualitative data, particularly in research where the ideas and concepts take shape or emerge as data accumulate. It helps the researcher manage the data, while creating and developing ideas and theories as understanding of the phenomena being observed grows (QSR, 2002).

Once transcribed, the interview data was imported into N6 and divided into text units, which serve as the basic data unit. The data was then reviewed and coding was applied to data units in order to identify key thoughts or ideas represented in the data - the open coding phase of the grounded theory analysis. As the research proceeded and iterated through the various phases, the key meaning of the data became clearer, which allowed the categories developed during the open phase of the coding to be changed, combined, expanded, split and rearranged to reflect the relationships that were emerging.

The interviews were numbered and the numbers were used for tracking the data. Also, to ensure anonymity of participants, interviewees were referred to in any published excerpts from the transcriptions by interview number or initials only.

**Phases of the Grounded Theory Method**

The four primary phases or activities associated with the grounded theory method, specifically as elaborated by Strauss and Corbin (1990), are Open Coding, Axial Coding, Selective Coding, and Theory Development. These phases overlap to a great extent as data collection and analysis occur together, but in general the steps occur in this order. These steps of the grounded theory method provide a structured approach to development of theoretical concepts and constructs from a variety of data about a given phenomenon. When applied properly and consistently, this approach provides the rigor necessary to develop theory. Appendix B, presents a graphical illustration of the key steps of grounded theory and Exhibit 14 below provides an overview of these four phases.

**Exhibit 14. Phases of Grounded Theory Method (Adapted from Leedy and Ormrod, 2004, p. 141)**

| Phase | Activities |
|---|---|
| Open Coding | – Data broken apart and analyzed – thought-by-thought – looking for common categories or themes related to the phenomenon being observed<br>– Categories further amplified or characterized by identifying and defining associated properties (attributes or sub categories)<br>– Goal is to reduce data to series of separate and distinct themes that collectively describe the phenomenon of interest |
| Axial Coding | – Further amplifying of categories, identifying relationships, interconnections, or interdependencies between and among categories and sub-categories<br>– Goal is to describe each category in terms of conditions associated with it, circumstances in which it is embedded, etc.<br>– Process iterates back and forth between data collection and coding (open and axial), continuing to refine categories and interconnections |
| Selective Coding | – Process of tying it all back together<br>– Categories, relationships, interconnections are combined<br>– Storyline developed to describe the phenomenon - what happens and how<br>– Researcher remains in touch with the data, so theoretical concepts being constructed remain grounded in the data |
| Theory Development | – Theory developed<br>– Can be in the form of a statement of the theory, a model that represents the concept, or some other representation<br>– Goal is a theory that captures the phenomenon and the associated relationships, interconnections, dependencies |

For this research, the analysis began as the transcribed interviews were imported into N6, the analysis tool. Employing the grounded theory concept of collection and analysis occurring in an overlapping, cyclical fashion, analysis of the first interviews began before all of the interviews were completed. As each interview was imported, the 'text unit' was set to break the data apart by numbering each line of the document as a separate and distinct text unit. This allowed the open coding analysis to look at individual blocks of data, one at a time. As each interview was analyzed in this fashion, text units that captured a concept or idea or theme that was relevant to complex system context were coded as a 'category' and identified with a term or descriptive phrase that captured the theme. As new text units were found to be coded, they were either grouped into an existing category, or a new category was created to capture that theme. As described in Exhibit 14, the open coding phase continued even as the research moved into initial considerations for the axial coding phase, so the number of categories waxed and waned as themes were split, merged, subordinated, and related. However, at the maximum state in the open coding phase, after all of the interviews had been initially reviewed and coded, there were in excess of 50 categories identified. Appendix C shows a listing of the categories that existed at this stage of the process. At this point, the emphasis shifted more significantly to the axial coding phase.

During the axial coding phase, the focus was to add further amplification to the existing categories with a great deal of emphasis placed on identifying relationships. During this phase, as the interviewing proceeded it became clear that the interviews were no longer rendering new substantive information and interviewing was ceased. This point of saturation will be discussed further in Chapter V. Each of the interview transcriptions was re-analyzed several times during axial coding in an attempt to glean additional categories. The N6 software was of great value during this phase because of the many tools it provides for querying across and between categories to identify relationships and make connections. This allowed the categories to be fleshed out and groupings began to become evident. For example, it was identified in the early stages of axial coding that the categories appeared to be aligning into four major groupings (shown in Appendix D), a fact that would prove to be significant when it came time to develop the grounded theory. As axial coding proceeded, key conceptual themes, relationships and patterns began to emerge. This signaled the transition to selective coding.

Because of the rigor applied during the axial coding phase, selective coding progressed rather rapidly, in part due to the fact that once again the move from axial coding to selective coding was not a hard cutover. Rather, as relationships became clearer during axial coding, the storyline began to emerge from the data. The story that was developed described what the phenomenon known as complex system context was, how it existed, how it was identified and how it was related to a specific complex system or complex system problem. One important part of this phase was moving from the grounded theory categories to the concept of elements of complex system context. Appendix E provides an illustration of this process. The storyline provided a natural and logical conduit from the data to the development of the grounded theory of complex system context. The detailed specific results of this grounded theory analysis are enumerated in Chapter V.

There are, however, concerns that must be addressed regarding the reliability and validity of the theories developed using the grounded theory method.

## RESEARCH VALIDITY AND RELIABILITY

While Glaser and Strauss (1967) assert that in their original text they "raised doubts about the applicability of these canons of rigor as proper criteria for judging the credibility of theory based on the use of this methodology." They suggest that grounded theories and grounded theory method should be judged based on "the detailed elements of the actual strategies used for collecting, coding, analyzing, and presenting data when generating theory, and on the way in which people read the theory" (Glaser and Strauss, 1967, p. 224). As discussed in Chapter III, the creators of the grounded theory method assert that their approach incorporates elements necessary to ensure the overall quality or goodness of research conducted within it framework by addressing qualitative benchmarks such as credibility, transferability, dependability, and confirmability/auditability (Lincoln and Guba, 1985; Guba and Lincoln, 1994).

**Validity**

The following list illustrates some of the specific elements of the grounded theory method in general, and this research design specifically, that supported the attainment of these qualitative criteria are:

- **Constant comparative method:** one of the primary guideposts of grounded theory method. "Rigour and credibility should stem from full and reflexive interrogation of the data in order to allow theory to emerge" (Goulding, 1998, p. 57). This supports credibility through developing and comparing various perspectives, and also through ensuring the accurate description and conceptualization of phenomena. This also helps meet dependability criteria by supporting the researcher's ability to assess changes in the phenomena based on time or contextual differences.
- **Theoretical sampling:** Sampling is driven by the theory as it emerges. This supports transferability, to the degree the researcher intends the research finding to be generalizable (see below re transferability), by

ensuring a purposive approach to sampling. It also supports overall research transparency.

- **Member checking:** Presenting to each participant the researcher's interpretations of their perspectives and experiences regarding the phenomenon of interest to ensure the researcher has accurately captured their accounts – "This process is called 'member checking' and is an invited assessment of the investigator's meaning" (Riley, 1996, p. 36-7).
- **Delimiting intended transferability:** "While some grounded theorists take the research into a variety of settings… it is not necessarily a condition for all grounded theory research, the aim of which is parsimony and fidelity to the data" (Goulding, 1998, p. 55). Grounded theory stresses that the researcher must be aware the need to ensure alignment between sampling/analysis approach, and the breadth of transferability intended and being claimed.
- **Inductive / theory-building approach:** One of grounded theory method's most notable strengths in establishing credibility as rigorous research is the researcher's ability to show the tie between the data and the theoretical constructions being developed, which is at the core of the grounded theory method approach. Through transparency of analysis, the researcher can demonstrate how the grounded theories (substantive or formal) were derived.
- **Use of a qualitative research tool:** The N6 software application used in the data collection and analysis phases was specifically designed to

assist researchers in developing and maintaining structure and rigor in the application of qualitative research approaches, and specifically the grounded theory method. Use of this tool added to the overall credibility of the research by ensuring a rigorous, disciplined analytical approach was followed.

**Reliability**

Similar to the concerns with validity are those related to reliability. In research endeavors, reliability refers to repeatability or consistency of a measure or observation. While there is always error associated with any measure, the goal in this instance is to minimize the variance of the measure or observation across multiple repetitions. In the case of this study, the issue of reliability has to do with the degree to which the observations and decisions made by the researcher could be repeated were the study performed by another researcher (Cresswell, 1994; Trochim, 2001). In order to increase the level of reliability for this study, the researcher employed the following techniques:

- **Identifying reliability-related limitations:** Concerns regarding matters related to achieving reliability such as those stemming from selection of participants, interviewing approach, and the researcher's philosophical perspectives have been addressed specifically throughout this document.
- **Peer reviews:** A peer review team was established consisting of two students enrolled in the Old Dominion University Engineering Management and Systems Engineering PhD program. The same two individuals participated throughout the research. This team conducted a

total of four peer reviews over the course of the research (during - open coding, axial coding, selective coding, and theory/framework construction). These reviews incorporated in the research a means for having other researchers audit and verify the approach taken, and the decisions made by the researcher. This process proved to be invaluable to the entire research process. Appendix F provides an overview of the peer review process and Appendix G presents the significant outcomes of the four peer reviews.

- **Traceability verification:** In addition to the reviewers above, a separate analysis of the CSCF was conducted to ensure traceability from the data to the grounded theory of complex system context to the various elements of the framework. This demonstrated that the study remained grounded in the data and ensured the research attained the level of credibility associated with grounded theory as envisioned by its founders. This reviewer was a systems expert meeting both the academic and experiential criteria specified for the interview participants.

Through the meticulous adherence to the grounded theory method, implementation of the techniques listed above, and establishment of transparency of all actions and decisions, the maximum level of research validity and reliability was attained in this research.

**CHAPTER SUMMARY**

This chapter presented the methodology employed in conducting this research. Beginning with a detailed explanation of the research design, the discussion in the first section included a description of the research design schema and the two phases of the research, the theory development phase and the framework development phase. The focus then shifted to the execution of the data collection and analysis strategy, including a discussion of the selection process employed in carrying out the purposive sampling strategy, a description of the interview process, and a detailed description of the data analysis including a presentation of the phases of the grounded theory method. The chapter ended with a discussion of those actions taken as part of the research methodology to ensure the validity and reliability of the research.

The following chapter, Chapter V, presents the results of the research, including a detailed description of the elements of complex system context, the development of the grounded theory of complex system context, and introduction to the Complex System Contextual Framework (CSCF).

# CHAPTER V

# RESEARCH RESULTS AND THEORETICAL CONSTRUCTION

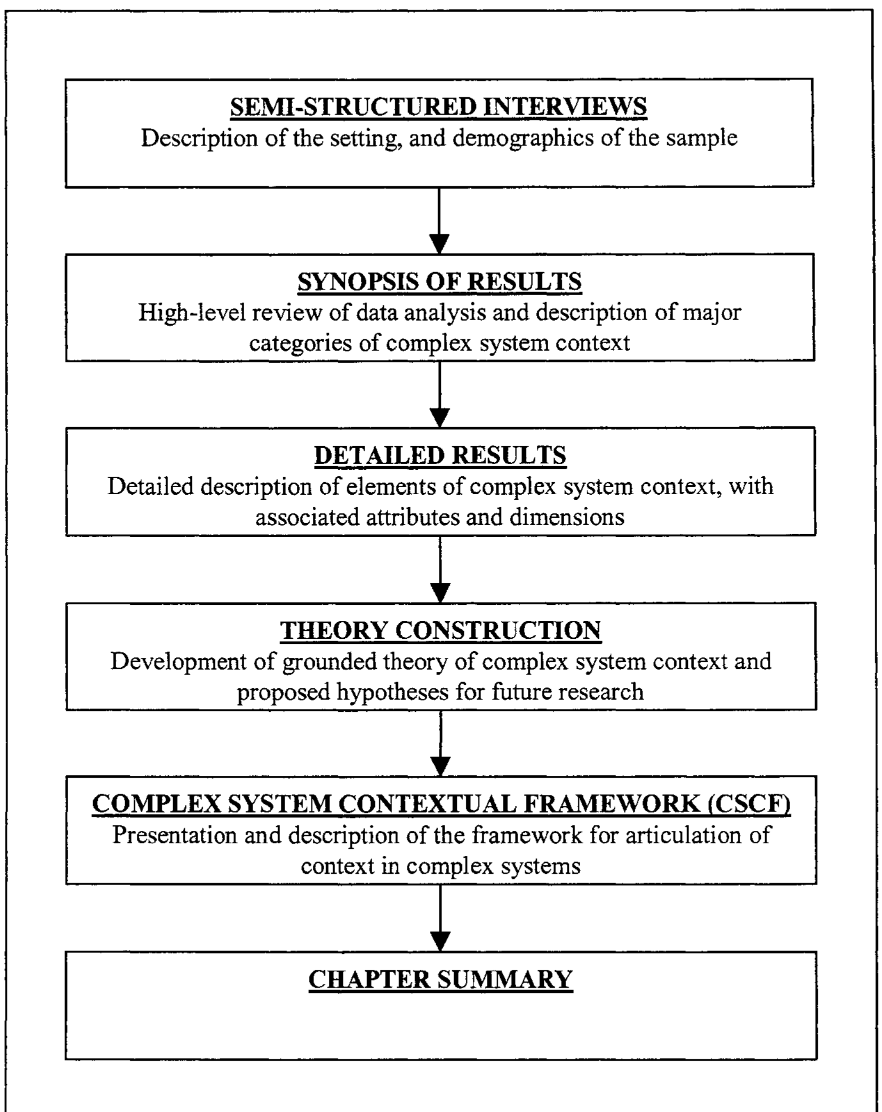
As presented in Chapter I, the purpose of this research was to develop a theoretical construct of complex system context in order to address the lack of detailed rigorous research, increase the depth of understanding of the concept of context, and develop a foundation for creation of a framework whereby complex system context could be captured and articulated as part of various systems-based approaches to complex system problems. Specifically, the research was focused on addressing two questions:

1. What are the constituent elements of complex system context, and what attributes and dimensions characterize these elements?
2. What systems-based framework can be developed for constructing and articulating complex system context?

To accomplish this, the grounded theory method was used to collect and analyze a variety of data, primarily qualitative data from a series of semi-structured interviews. Chapter III discussed the research perspective from which this analysis was undertaken and Chapter IV presented the research methodology that was employed in conducting these interviews, collecting and analyzing the qualitative data, and developing the theoretical construct.

This chapter presents the results of this qualitative analysis. The discussion begins with a description of the semi-structured interviews, followed by a broad structure for and high-level view of the results of the analysis of the data. Each of the key concepts or themes that emerged during the analysis is then discussed in detail and its 'fit' into the overall theoretical construct is explained. The fully integrated theory is then presented, followed by presentation of the Complex System Contextual Framework (CSCF). Exhibit 15 below presents a diagram of the layout of Chapter V, illustrating the organization and flow of the discussion of the research results.

**Exhibit 15: Chapter V Layout Diagram**



## SEMI-STRUCTURED INTERVIEWS

As discussed in Chapter IV, the primary source for the qualitative data used in this research was a series of semi-structured interviews. Following the grounded theory method, the interview process involved conducting data collection and analysis in parallel using the constant comparative method, continually going back to the data as the analysis progressed to ensure that as categories and concepts emerged the developing theoretical constructs were properly supported or grounded in the data, and to ensure the continued employment of theoretical sampling by adjusting the sampling focus based on the emergent conceptual themes.

### Setting and Sample

Using the criteria specified in Chapter IV for participant selection, a list of potential interview candidates was developed, beginning with individuals the author knew who met either the academic or experience selection criteria. The list of participants was then expanded based on references from those individuals and others. Keeping in mind the goal of the research data collection strategy for using a maximum variation sampling approach (Patton, 1987), potential participants were also evaluated to ensure a those selected would provide variation of experiential and educational backgrounds. Interviewing began and sessions were conducted as they could be arranged given schedule and geographical constraints, with the average interview length being one hour (minimum 40 minutes / maximum 1.5 hours). The interviewing was stopped after a total of twelve (12) interviews were conducted because no new concepts were being identified and no additional grounded theory categories were being created in the process of axial coding during the ongoing analysis, indicating that the emergent categories had reached saturation.

As delineated in Chapter IV, the selection of participants was based on their having 'significant education' and/or 'significant experience' within the systems domain, specifically looking at the analysis of complex systems and complex system problems. Exhibit 16 provides a summary of each interview participant's qualification under these selection criteria. Appendix H provides a graphical format for comparison of the interviewees' qualifications.

**Exhibit 16. Summary of Interview Participant Qualifications**

| Interview # | Education | Systems Education Criteria | Years of Systems Experience | Areas of Systems Experience | Experience Criteria |
|---|---|---|---|---|---|
| 1 | MS - National Security Affairs<br>BS - Naval Architecture | No | 6 | **Systems Experience: Department of Defense/Industry**<br>Systems of Systems Analysis concept development | Yes |
| 2 | BA - Government and Foreign Affairs<br>MS - Operations Research<br>Federal Executive Fellow - RAND Corp | Yes | 5 | **Systems Experience: Department of Defense/Other Government/ Industry**<br>Operations Research Analyst/Strategic Planner | Yes |
| 3 | PhD - Mechanical Engineering<br>MS - Operations Analysis<br>BSAE - Aerospace Engineering<br>Professional Engineer | Yes | 12 | **Systems Experience: Department of Defense/Other Government/ Industry**<br>Operations Analysis and Systems Engineering / Strategic Planning | Yes |
| 4 | PhD - Operations Research<br>BS - Applied Mathematics / Minor - Pol Sci | Yes | 5 | **Systems Experience: Department of Defense/Other Government/Industry/Academia**<br>Operations Research Analysis / Systems Engineering / Systems of Systems | Yes |
| 5 | MPS - Political Science<br>BS - Mechanical Engineering | No | 6 | **Systems Experience: Department of Defense/Other Government**<br>Systems of Systems Analysis concept development | Yes |
| 6 | PhD - Business<br>MBA<br>MA - Communictaions<br>BS - Printing Management & Technology / Psychology | No | 7 | **Systems Experience: Other Government / Academia**<br>Fifteen years experience as member of university faculty / administration (seven years post-PhD). | Yes |
| 7 | MS - Operations Research<br>MS - Systems Engineering (In progress)<br>BS - Nuclear Engineering | Yes | 13 | **Systems Experience: Department of Defense/Academia - Applied Research/Other Government**<br>Operations Research/Systems Enginerring Defense and Space Systems | Yes |
| 8 | PhD - Systems Engineering<br>MS - Systems Sciences<br>BE - Electrical Engineering | Yes | 15 | **Systems Experience: Department of Defense/Other Government/ Industry/Academia**<br>Fifteen years post-PhD experience. Focus areas: numerous studies modeling the U.S. National Airspace System (NAS) | Yes |
| 9 | PhD - Mechanics<br>ScM - Applied Mathematics<br>BS - Electrical Engineering<br>Senior Executive Fellow Program | No | 42 | **Systems Experience: Department of Defense/Other Government/ Industry/Academia**<br>Forty-two years post-PhD experience. Focus Areas: Mathematical models, Statistics, Quantitative analysis of uncertainty in cost estimates | Yes |
| 10 | BS - Operations Research / Industrial Engineering | No | 24 | **Systems Experience: Department of Defense/Other Government**<br>Twenty-four years experience as a Operations Research/Systems Analyst | Yes |
| 11 | PhD - International Studies - Candidate, ABD<br>MS - Education<br>MS - National Security and Strategic Studies<br>MSA - Administration<br>AB - Government | Yes ** | 10 | **Systems Experience: Department of Defense/Other Government**<br>Systems of Systems Analysis concept development | Yes |
| 12 | PhD - Decision and Control Systems<br>SM - Decision and Control Systems<br>MBA - Managerial Economics<br>MS - Nuclear Engineering<br>BS - Engineering Physics | Yes | 35 | **Systems Experience: Department of Defense/Other Government/Industry/ Academia**<br>Thirty-five years post-PhD experience, President and CEO American Management Association International; Chairman/CEO of several corporations; Indiana Commissioner for Higher Education; administration/faculty Harvard University & University of California at Berkeley | Yes |

** Note: Although area of study not in systems field, interviewee considered as meeting education criteria due to systems focus of PhD research

The following sections provide further characterization of the interview sample, including a summary of overall qualifications as delineated in the academic and experiential selection criteria as well as some basic demographic information.

*Academic/Educational Criteria*

Of the twelve participants interviewed, six had doctorate degrees and all but one had graduate degrees. Seven of the participants were considered qualified under the academic criteria. Six of them had graduate degrees that clearly met the selection criteria for significant systems-related education, with qualifying graduate degrees including – Decision and Control Systems, Operations Analysis, Systems Engineering, Systems Sciences, and Operations Research. The seventh who was counted as qualified was an exception. At the time of the interview, he was a doctoral candidate conducting dissertation research that was focused on the application of a system of systems analytical approach. Even though his degree program was from a non-systems-related curriculum (International Studies), his research was within the systems domain and as such he had done an extensive amount of research in systems theory and principles. Based on this, he was considered as meeting the educational criteria for advanced studies in a field related to systems approaches.

*Experiential Criteria*

Significant experience was defined earlier as three or more years of work (individually or as part of a team) on initiatives involving the analysis of complex systems or complex systems problems. All of the participants met the minimum selection criteria for this area, with several of them greatly exceeding it. Systems-related experience levels ranged from 3 years for the least experienced, to two participants who had 35 years and 42 years of post-PhD experience respectively, applying various systems-based approaches to complex system problems. The experience also crossed a broad spectrum of domains of application, with 11 having experience applying systems approaches within an organization associated with defense, 7 had experience in other (non-defense) government agencies, 5 had experience in non-defense-related private industry, and 6 had experience in academia as faculty and/or administers at the college or university level.

*Demographics*

All twelve of the interview participants were male; eleven of the twelve participants were Caucasian and one was Chinese. Diversity of systems-specific experience and background was taken into consideration, however gender, nationality, ethnicity, etc. were not considered germane to the research; and as such, were not a factor in the selection process. While several of the initially identified potential candidates were female, they were not included in the sampling process either because they did not meet the selection criteria or because scheduling conflicts precluded arranging interviews with them during the timeframe prior to completion of interviewing. A possible future extension of this research would be investigating whether these aspects have any relationship to perceptions of complex system context.

As shown, the participants brought a significant depth and breadth of systems knowledge and practice to the interview process and provided a rich source of qualitative data with regard to the various approaches to dealing with complex system problems. During the interviews, the participants discussed their experiences and observations across a wide range of applications of systems approaches. The next section presents a synopsis of the results of the analysis.

## SYNOPSIS OF RESULTS

This section provides a high-level review of the results of the data analysis and presents a description of major categories of complex system context. Detailed results will be presented later in this chapter.

It was determined early in the research that it was important to clearly delineate how the research was looking at complex system context. To do this a research perspective of complex system context that was established in Chapter II. This perspective was created to support the planning and development of the research and to ensure that the effort was properly bounded. Exhibit 17 restates the initial perspective of complex system context.

**Exhibit 17. Research Perspective of Complex System Context**

| **Complex system Context** |
|---|
| Includes events, incidents, factors, settings, or circumstances that in some way act on or interact with the system, perhaps as enabling or constraining factors; |
| Includes an 'enacted' environment (Weick, 1995), which captures system/environment interactions and interdependencies, however, system context and system environment are conceptually distinguishable; |
| Is a construct or interpretation of properties of a system that are necessary to provide meaning to the system, above and beyond what is objectively observable; |
| Is reflexive in nature, resulting in context further defining the system while the elements of the system are part of the self-same context; and |
| Does not have a single true reality or correct interpretation of context, indicating that the principle of complementarity applies equally to system context as to the system itself. |

As the data collected in the interviews and additional documentary data was analyzed, several core categories or themes related to the concept of complex system context emerged, providing a high-level response, to the first part of the first research question:

***'What are the constituent elements of complex system context...'***

As the data was analyzed, the concepts associated with the elements of complex system context emerged from the data and can be summarized in several high-level central themes that were identified. Based upon these themes, the concept of complex system context is characterized as being influenced by:

- the roles individuals carryout as part of the complex system and/or that are part of the application of a systems based approach to analyzing the complex system or complex system problem;
- perspectives of those individuals and/or groups of individuals;
- the process of constructing a systems view of the complex system or complex system problem under study;

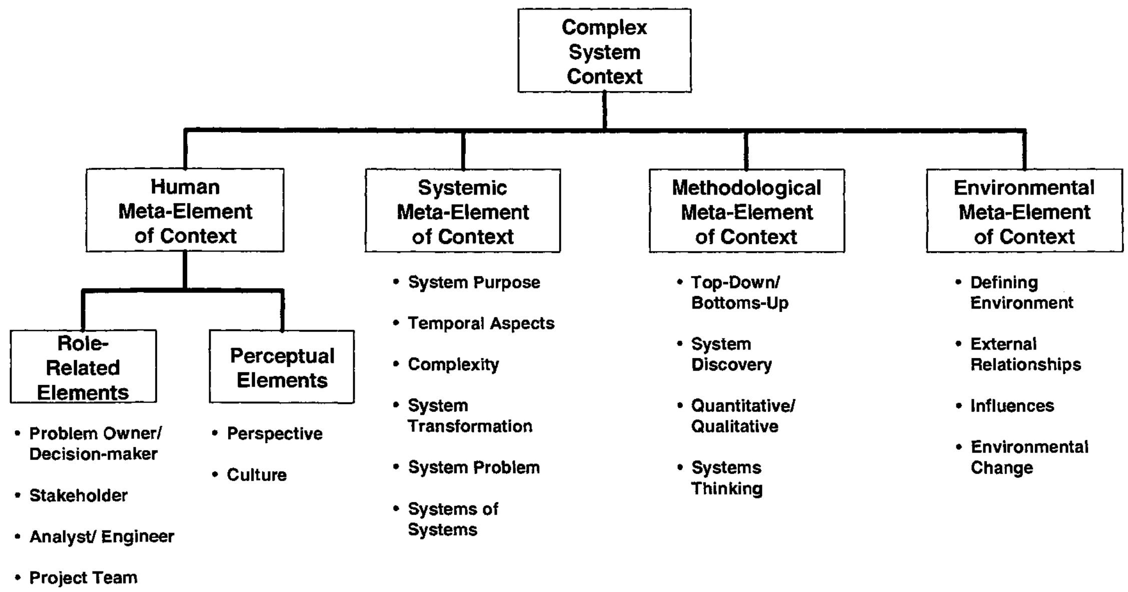
- the methodological approaches considered and adopted for addressing the system in question;
- the environment of the system of interest.

These themes emerged over the course of the constant comparative data collection and analysis process; however, they truly crystallized and stood out as the research moved from the axial coding phase into selective coding. Four top-level collective categories or groupings of the elements of complex system context emerged from these concepts. These major categories of elements, referred to as meta-elements, were created during the analysis to capture emergent contextual concepts. Additional information will be provided in the following sections about each of the meta-elements.

- **The Human Meta-Element** – related to the various aspects of human involvement in complex systems, specifically looking at the roles people play and the perspectives they bring
- **The Systemic Meta-Element** – related to the various aspects of dealing with complex systems that stem from systemic principles and concepts, and from taking a systems view
- **The Methodological Meta-Element** – related to the aspects of dealing with complex systems that stem from specific approaches or methodologies being applied or considered for application
- **The Environmental Meta-Element** – related to the aspects of dealing with complex systems that are related to the system's environment

The meta-elements were further broken down into a hierarchical taxonomy of the elements of complex system context, graphically represented in Exhibit 18 below.

**Exhibit 18. Taxonomy of Elements of Complex System Context**




This section provided a very high level description of the results of the research and introduced the resultant taxonomy of the elements of complex system context. With this broad structure in mind, the next section presents a detailed discussion of the data analysis process and the resultant findings, showing the repetitive aggregation and decomposition of the constant comparative process; the categories that emerged; their connection to and grounding in the data; and the relationships that were identified.

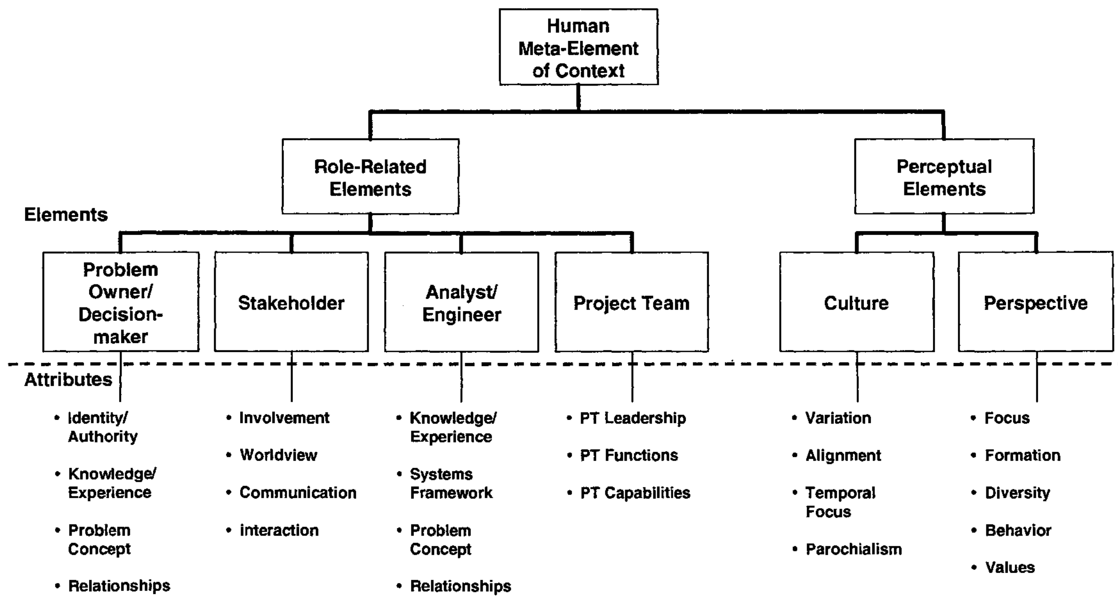
## DETAILED RESULTS

In the following sections, the four contextual meta-elements are described in detail, presenting a discussion of how these concepts emerged and were constructed. While this section makes reference to the data, it does not include specific extracts from the raw data to support of the elaboration of the elements of context because the expansive volume of data that would have been involved would have made this discussion too cumbersome. More detailed descriptions of two the elements of complex system context, including data extracts from the interviews to support the emergence of that specific elements, attributes and dimensions, are presented in Appendices I and J.

*Detailed Description – Human Meta-Element*

During the axial coding process a common theme emerged among coding 'nodes' (as referred to in N6 terminology) referring to the various roles people play either as part of a particular complex system of interest or in dealing with complex systems. In addition to the characteristics associated with roles, a related theme emerged involving contextual aspects related to the perspectives people bring to the system. These nodes were combined into a category that was initially named 'the people' and then 'human influences' before it was determined that it was actually emerging as one of the meta-elements of context, at which time the name was changed to its final designation of *Human Meta-Element of Context.* The Human Meta-Element consists of two primary sub-categories: Role-related Elements and Perceptual Elements. In the following discussion of these subcategories, each of the contextual elements is described. Exhibit 19 Below provides a graphical representation of the Human Meta-Element of Context and the attributes associated with each of the related elements.

**Exhibit 19. Human Meta-Element of Complex System Context**




*Human Meta-Element – Role-Related Elements Subcategory*

Observations concerning key roles within the system formed the foundation for emergence of the elements within the sub-category of role-related human elements. The four elements of context within this sub-category are: Problem Owner/Decision-maker, Stakeholder, Analyst/Engineer, and Project Team.

*Human Meta-Element – Role-Related – Problem Owner/Decision-Maker*

The first Role-Related Human Element to be presented is Problem Owner/Decision-Maker (PODM). This refers to an individual or group who, because of their position within the organization or system, is (are) responsible for making decisions concerning the complex system and complex system problem of interest. The analysis showed that the PODM is a critical role in any systems engineering or systems analysis initiative involving complex systems and the manner in which the PODM interacts with the system and the engineering effort is key to being able to successfully apply a systems approach to a complex system problem. Four attributes were identified in association with this element of context: Identity/Authority; Knowledge/Experience; Problem Concept; and Relations. Exhibit 20 below shows the attributes and associated dimensions of the element Problem Owner/Decision-maker.

**Exhibit 20. Problem Owner/Decision-Maker – Attributes and Dimensions**

| Attributes | Dimensions |
|---|---|
| **Identity/Authority** | Identification; Number; Process; Designation; Resource Control |
| **Knowledge/Experience** | Domain Knowledge; Systems Knowledge; Decision-making Experience |
| **Problem Concept** | Expectations; Concept Flexibility; Constraints/Limitations; Objectives |
| **Relationships** | Stakeholder Relationships; Direct Support Roles |

The first attribute associated with the PODM is *Identity/Authority*, referring to the identification and make up of the PODM, and the range of authority associated with this role. This attribute addresses issues such as: Is the PODM clearly identified? Is the PODM a single individual or a group? Do all who need to know, have a clear understanding of the PODM as defined within the system of interest? Does the PODM have control over the requisite system resources to implement decisions that are made? During the interviews, terms such as customer or client, were frequently used interchangeably with the concept of PODM.

Another attribute that emerged as critical was the level of *Knowledge/Experience* of the PODM. This attribute considers the ability of the PODM to understand the system in which the problem lies, the approach being taken to address it, and the process of making complex decisions. Those aspects of the PODM associated with their level of knowledge within the domain of the system of interest

(Domain Knowledge); level of knowledge of systems concepts, principles and approaches (Systems Knowledge), and level of experience in a decision-making role (Decision-making Experience) are crucial to the successful application a systems approach to a complex system problem.

It became clear during the analysis that the way in which the PODM viewed the problem and the solution space played a pivotal role in the engineering or analysis efforts. It was important to understand how much, if any, preconception was in play and as a result how much flexibility those attempting to address the problem had. This led to the identification of the PODM attribute labeled *Problem Concept.* This attribute is defined as to what degree the PODM had established expectations for the initiative; the amount of flexibility the PODM had in the conceptualization of the problem, the kinds of constraints or limitations imposed on or by the PODM regarding the problem and approaches for dealing with it, and whether specific objectives had been set for the initiative. The dimensions associated with Problem Concept are: Expectations; Concept Flexibility; Constraints/Limitations; and Objectives.

The fourth attribute identified under the PODM element of context was *Relationships*. During the analysis, the concept emerged that there were key relationships that affected the PODM and/or the decision-making process. Most critical were the PODM's relationships with other system stakeholders and with individuals who provided direct support to the PODM and associated processes. While the relationships among all stakeholders are important, considering the unique role of PODM, there is additional emphasis placed on how the PODM relates to others. This attribute emerged during the analysis as a theme that centered on a number of comments made about the PODM's dealings with others and also the degree to which the PODM does/can delegate decision-making functions to individuals in support roles. The dimensions associated with the attribute *Relationships* are: Stakeholder Relationships; Direct Support Roles.

*Human Meta-Element – Role-Related – Stakeholder*

Similar in concept to the PODM as an element of context is that of the *Stakeholder*. For the purpose of this research, a stakeholder is an individual, group, entity, or organization that has some interest or involvement (ownership, resourcing, support, membership) in the complex system of interest; can be affected by the system or can influence it; or is either directly or indirectly impacted by the system. The analysis showed that the degree to which stakeholders buy-in to the approach, their perspectives regarding the complex system and complex system problem, the manner in which they communicate, and their key relationships are significant factors in complex systems. Four attributes were identified in association with this element of context: Involvement; Worldviews; Communications; and Interaction. Exhibit 21 below shows the attributes and associated dimensions of the Stakeholder element of context.

**Exhibit 21. Stakeholder – Attributes and Dimensions**

| Attributes | Dimensions |
|---|---|
| **Involvement** | Size; Type; Commitment |
| **Worldview** | Focus; Range; Flexibility |
| **Communication** | Inter-stakeholder; Analysts/Engineers |
| **Interaction** | Leadership; Personalities; Politics |

*Involvement* is the first attribute of the contextual element called *Stakeholder*. The attribute *Involvement* characterizes the stakeholders as a group, and why and how specific stakeholders are concerned with the system of interest. The analysis indicates that it is important upfront to know the size of the stakeholder group (Size). Additional concepts that emerged as dimensions of stakeholder involvement included the importance of understanding, for individual stakeholders, the type of association the stakeholder has with the complex system (Type), and to what degree has the stakeholder 'bought-in' to or is willingly committed to their role in association with the complex system and in addressing the complex system problem (Commitment).

In the process of analyzing the data, the concept of *Worldview* emerged as another attribute of the element *Stakeholder*. While the concept of worldview will be touched upon in the discussion of other elements, its importance in the discussion of stakeholders was central to understanding why the stakeholder role was so pivotal to the system and particularly to any initiative intended to change or improve the system. The dimensions associated with characterizing *Worldview* are Focus, Range, and Flexibility. Focus refers to whether the stakeholder worldviews are stakes-based or system-based, in other words, whether the primary motivations of the stakeholders tend to be centered on their own personal/organizational interests or on the interests of the complex system of interest. Range is an indicator of the breadth of differences in worldview among stakeholders. Flexibility has to do with whether stakeholders' worldviews are rigidly fixed or somewhat malleable to the views of others.

Early in the analysis, it became clear that stakeholder *Communications* was emerging as a key attribute of the *Stakeholder* element. In order to function properly within the complex system or complex system problem initiative, stakeholders must develop effective communication channels among themselves (Inter-stakeholder) and with those involved in application of the systems approach (Analysts/Engineers). All of these connections are important to the stakeholder's ability to function within the system and be effective. Without the proper communication channels, stakeholders would not be able to understand the system, because no one stakeholder has full visibility on what the system is, what it is doing, and what problems it is experiencing.

*Human Meta-Element – Role-Related – Analyst/Engineer*

The third Role-Related element is that of *Analyst/Engineer* (A/E). This element focuses on those aspects of this role that are significant factors or influences within the complex system or in dealing with a complex system problem. The term analyst/engineer, as used here, refers to the individual(s) who have been assigned the role of actually doing the hands-on work of dealing with the complex system problem of interest to the PODM. Rather than being the decision-maker, the A/E's role is to perform some type of systemic analysis, report findings, develop solutions/options, make recommendations to the individual or group in the PODM role, and sometimes, even to implement the newly engineered or reengineered solution. The data analysis in this research showed that there are four attributes of the A/E element of context that are key. Those key attributes of A/E are: their knowledge and experience – individually and collectively (Knowledge/Experience); the approach to systems or the framework they are inclined to apply – meaning how they think about systems and how they apply their ideas (Systems Framework); their view of complex system problems in general and their concept of the specific complex system problem of interest (Problem Concept); and lastly, their relationships to and within the system (Relationships). The attributes of the Analyst/Engineer element of context and their associated dimensions are shown in Exhibit 22 below and discussed in the sections that follow.

**Exhibit 22. Analyst/Engineer – Attributes and Dimensions**

| Attributes | Dimensions |
|---|---|
| **Knowledge/Experience** | Domain Knowledge; Systems Knowledge; Access to Experts |
| **Systems Framework** | Philosophy; Methodologies; Tools |
| **Problem Concept** | Expectations; Concept Flexibility; Constraints/Limitations; Objectives |
| **Relationships** | PODM; Stakeholders; Confidence; Authority |

The analysis of the grounded theory category for the *Analyst/Engineer* element of context revealed the importance of the knowledge and experience of those performing this role, resulting in the emergence of the *Knowledge/Experience* attribute. Three major factors in this area are considered critical to accurately capturing the characteristics of this attribute surfaced as appropriate dimensions – Domain Knowledge; Systems Knowledge; Access to Experts. Similar to the discussion for PODM, Domain Knowledge is associated with A/E's level of knowledge within the domain of the complex system of interest, while Systems Knowledge refers to their level of knowledge of systems concepts, principles and approaches. Different from the PODM, is the need that was identified for A/E's to be able to rapidly increase their level of knowledge (primarily in the domain area), usually by tapping into the knowledge/experience of subject matter experts, which was identified as the dimension Access to Experts.

Given that complex systems are constructs and the pivotal role of the A/E in constructing the view of the complex system/complex system problem of interest, it became apparent that the A/E's way of thinking about and working with systems was an important attribute to capture in complex system context. This aspect of the A/E element of context was captured in the attribute identified as *Systems Framework*, which is further characterized by three dimensions – the A/E's views and perceptions regarding systems as elaborated in Chapter III (Philosophy); the A/E's propensity toward applying specific systems-based methodologies and the range of methodological options they are able/willing to employ (Methodologies); and the variety of applications, tools, or models with which the A/E is proficient (Tools).

The analysis of the data pointed to the close link between A/E and PODM when it came to the way in which the complex system problem of interest and the associated solution space were viewed. It was important to understand if the Analyst/Engineer had preconceptions of the system/problem and if so, what degree of flexibility they could/would still accept in defining/conceptualizing the problem. This idea was captured in the A/E attribute labeled *Problem Concept*, which is characterized by the degree to which the A/E had established expectations for the initiative; the amount of flexibility the had in conceptualization of the problem, the kinds of constraints or limitations imposed on or by the A/E regarding the problem and approaches for dealing with it, and whether specific objectives had been set for the initiative. The dimensions associated with Problem Concept are: Expectations; Concept Flexibility; Constraints/Limitations; and Objectives.

The last attribute identified related to the Analyst/Engineer element of context was *Relationships*. Similar to the attributes of *Relationships* under the element PODM and *Interactions* under the element Stakeholder, *Relationships* under the element Analyst/Engineer focuses on the idea that there are key relationships associated with the A/E that affect how the complex system of interest is constructed and how it will be approached during any analysis/engineering effort. Most critical were the A/E's relationships with the PODM and system stakeholders. Two other aspects of *Relationships* emerged that had more to do with the skills and abilities of the A/E in dealing with others, looking at how confident the A/E was in their own role; and how well their level of authority was defined and how effectively they exercised it. This attribute emerged from several discussion threads in the interviews that touched upon the dealings the A/E had with others during the process of an analysis effort. The dimensions associated with the attribute Analyst/Engineer *Relationships* are: PODM; Stakeholders; Confidence; and Authority.

*Human Meta-Element – Role-Related – Project Team*

The element *Project Team* is the final element identified within the group of Role Related elements, and is actually a special case or an extension of the element *Analyst/Engineer* (A/E). This element addresses those human, role-related aspects of complex system context that stem from the instantiation of a systems engineering / systems analysis 'project team' to address the identified complex system problem. The *Project Team* element specifically focuses on the team-related aspects of the effort, rather than those individual aspects already considered in the *Analyst/Engineer* element of context. Three attributes of the contextual element *Project Team (PT)* emerged from the analysis: the significant influence of the 'team leader' on the overall impact of project team on system context (PT Leadership); the key functions that the project team performs as an entity that influence context (PT Functions); and lastly, the influence of the capabilities the project team brings together and how they approach and address the system/problem of interest (PT Capabilities). These attributes and the dimensions associated with each of them (as shown in Exhibit 23 below) are illustrated in the following paragraphs.

**Exhibit 23. Project Team – Attributes and Dimensions**

| Attributes | Dimensions |
|---|---|
| **PT Leadership** | Designation; Leadership Approach |
| **PT Functions** | Integration; Arbitration; Conceptualization; Collaboration |
| **PT Capabilities** | Team Skills; Tools; Lexicon; Perspectives; Consensus |

The first attribute of the *Project Team* element of context to be presented focuses on the leader of the project team. This leader may either be a formally assigned project manager, project engineer, or team leader; or they may be in a less formal leadership role due to their knowledge, experience, and leadership abilities. The dimensions that characterize this *PT Leadership* are Designation, and Leadership Approach. The manner by which the leader is designated, e.g., formally or informally, assigned or selected/elected from a group of peers is important because it can affect the influence exerted by the leader. Similarly, the data indicated that the approach taken by the leader in performing this role (e.g., directive, authoritarian, collaborative, etc.) was a major factor in the success of the project team.

The data showed that there were several key functions that were part of a successful complex system problem project team. From this theme, the *Project Team* attribute *PT Functions* emerged. The principal characteristics of this attribute were captured in four dimensions, which illustrate how effectively the team performs the functions of Integration, Arbitration, Conceptualization, and Collaboration. Integration is the function whereby the different aspects of the systems analysis are synthesized into a single team product. Arbitration is a measure of how well the project team is able to settle differences in perspectives or views of things such as the system, the problem, or the methodology to be applied. The dimension called Conceptualization is the aspect of the project team's ability to generate new concepts or ideas during the engineering/analysis process. Lastly, Collaboration provides a way of illustrating the degree to which the team is able to effectively cooperate and work together.

The final *Project Team* attribute is *PT Capabilities*, which provides a means of characterizing the team's combined abilities, skills, and means for accomplishing the task. Three dimensions emerged for this element of context. Team Skills represents an holistic view of the skill set possessed by the team and is a combination of the team's systems and domain expertise. The dimension Tools looks at the applications, methodologies, models, etc. that the team has at its disposal for the analysis/engineering effort. Lastly, Lexicon indicates whether the team has established and documented a project-specific lexicon that clearly delineates the terminology used to approach the complex system of interest.

*Human Meta-Element – Perceptual Elements Subcategory*

In addition to the elements of context related to various roles, a second sub-category of the Human Meta-Element was identified relating to percepts held by the humans linked to a complex system. The Perceptual elements are those elements of context related to the worldviews or conceptualizations of individuals associated with the complex system; they include Perspective and Culture.

*Human Meta-Element – Perceptual – Perspective*

The first element from the Perceptual subcategory of the Human Meta-Element of context is *Perspective*. Although the term perspective can have a very broad interpretation, in this instance, where it is referring to a specific element of complex system context, the idea of perspective is more focused. Here, it is less about looking at specific perspectives and more about describing how different perspectives impact the definition, construction, and analysis of complex systems. As the concept of the contextual element *Perspective* emerged from the data, it was characterized by the following attributes: Variation; Alignment; Temporal Focus; and Parochialism. Exhibit 24 below shows the attributes and associated dimensions of the *Perspective* element of context.

**Exhibit 24. Perspective – Attributes and Dimensions**

| Attributes | Dimensions |
|---|---|
| **Variation** | Cross-View; Cross-Level; Disparity |
| **Alignment** | Acknowledgement; Discernment; Normalization |
| **Temporal Focus** | Focal Point; Range |
| **Parochialism** | Type; System/Subsystem-Level; Domain-Based |

The *Variation* attribute of the *Perspective* element is derived from the observed significant influence that differences in perspective or worldview can have on the ability of a complex system to perform effectively, and as a result often contributing to the existence of the complex system problem of interest. The first dimension of the *Variation* attribute specifically differentiates between different views of the system, e.g., a strategic- versus a tactical-view (Cross-View). Similarly, the second dimension differentiates between different levels within the system, e.g., the management- versus working-level (Cross-Level). The third dimension (Disparity) is a measure of the overall difference in perspectives that exist within the complex system.

The attribute *Alignment* refers to the ability (or willingness) of the system to address the problems created due to *Variation* of perceptions. In this sense, it is related to the *Variation*, but is capturing a different aspect of it. Three dimensions were identified associated with the *Alignment* attribute: Acknowledgement, Discernment, and Normalization. Acknowledgement is that aspect of alignment that requires the system to recognize the variation in perspectives that is present. Discernment is an indication of the system's ability to differentiate between or among the various perspectives and discover the full extent of the differences. Normalization shows that aspect of alignment that involves the systems ability to determine or establish a common perspective for the purpose of addressing the complex system of interest.

Another attribute of the *Perspective* contextual element is referred to as *Temporal Focus*. This attribute looks at perspectives from a time-based approach. What emerged from the data was that the time focus of perspectives within the system had a major impact on how the complex system functioned and how it was constructed in addressing the system of interest. The dimension Focal Point refers to where in time the perspective is focused, i.e., past/present/future, while Range is a reference to whether the perspective is long-range or short-range.

*Human Meta-Element – Perceptual – Culture*

*Culture* is the next element to be presented from within the Perceptual subcategory. The analysis indicated that system/organizational cultural aspects were an important element of system context. In this case, culture is referring to traditions, customs, and accepted behavior. *Culture* as an element of complex system context, then is looking at those traditions, customs, and behaviors within the complex system, which can be attributed to the relationships and behaviors of the people within the system. The analysis showed that the culture within the system was a factor in the ability of the system to function effectively and as the concept of *Culture* as an element of complex system context came together, four attributes (Focus, Formation, Diversity, and Behavior) emerged to appropriately describe those aspects of *Culture* that were considered important to capture. Exhibit 25 below shows the attributes and associated dimensions of *Culture*.

**Exhibit 25. Culture – Attributes and Dimensions**

| Attributes | Dimensions |
|---|---|
| **Focus** | External; Internal; Personal; Allegiances |
| **Formation** | Extant; Artificial |
| **Diversity** | Extent; Identity; Strength |
| **Behavior** | Dominance; Desired |
| **Values** | Recognition; Acceptance; Differentiation |

During the analysis of the data, there surfaced the idea that *Culture*, as an element of context, can appear in the system in several different manifestations, and that one of the distinguishing attributes was the cultural focus, or what was its origin. For example, the degree to which the culture that was influencing the system was actually originating from outside of the system (External) and/or originating within the system (Internal). The degree to which the culture was influenced by the desires of individuals in response to - 'What does it mean for me' (Personal), and the strength of the influence of loyalty or commitment individuals within the system had to other groups or other systems (Allegiances).

The concept of *Formation* as an attribute of the contextual element *Culture* came from a discussion about international politics and the viewing of nation-states as systems of systems. The point was raised that in some instances (e.g., Bosnia-Herzegovina) attempts were made to 'create' a culture by artificially trying to make a nation where there was no existing cultural bond. This is a unique instance, but similar activities have been noted in corporate mergers, acquisitions, etc. This discussion gave rise to the attribute of *Culture* referred to as *Formation*, which is characterized by two dimensions: Extant - referring to the culture that naturally emerges within the system; and Artificial – referring to a culture that is unnaturally designed or created for the system.

The number of instances where the idea of cultural differences or distinctions appeared in the data resulted in the development of *Diversity* as one of the attributes of the contextual element *Culture*. As the examples below illustrate there were three aspects of diversity that emerged from the analysis. It was considered important to determine specific cultural differences that exist within the system (Identity); the breadth of those differences or the degree of diversity within the system (Extent); and how ingrained or deep-rooted the culture diversity is (Strength).

Considering that one of the ways in which culture is evident is through the behavior of individuals and groups, *Behavior* emerged as one of the attributes of the element *Culture*. Two aspects of behavior were identified as appropriate dimensions for the attribute *Behavior* because they were considered germane to the concept of system context. It was determined that to articulate context, it was important to understand if there specific behaviors that were dominant within the system (Dominance). Similarly, it was important to determine if there were behaviors that could be identified as those that certain groups within the system considered preferable (Desired).

A final attribute of the *Culture* element of context that emerged during the analysis was the concept of *Values*. This was evident in the number of comments made during the interviews about the need to be able to determine or discern good versus bad or right versus wrong, or in some other way to assess the value or worth of various aspects of the system. The dimensions of the attribute *Values* establish several key aspects of how values are manifested in the system, considering the level to which the system's values have been formally recognized and documented (Recognition); the breadth of acceptance of an identifiable set of system values (Acceptance); and the degree to which the value system within the complex system of interest differs from that of its environment (Differentiation).

*Detailed Description – Systemic Meta-Element*

While it may seem reflexive or circular, there was also a common theme that emerged centering around the idea that complex systems are influenced by virtue of their being a construct of a systems approach. In other words, the system is affected because it is being viewed as and conceptually constructed as a system. As this theme emerged, the associated contextual elements were captured under another of the four major categories of system context. This major category captured those elements related to the various aspects in dealing with complex system problems that stem from systemic principles and concepts, from taking a systems view of a complex problem, and from concepts about different types of complex systems. Early in the analysis, this category was called 'The Problem System' and later 'Systemic Influences.' However, when it became apparent that this grouping was emerging as one of the top-level meta-elements of context elements, it was renamed *Systemic Meta-Element of Context.*

**Exhibit 26. Systemic Meta-Element of Complex System Context**

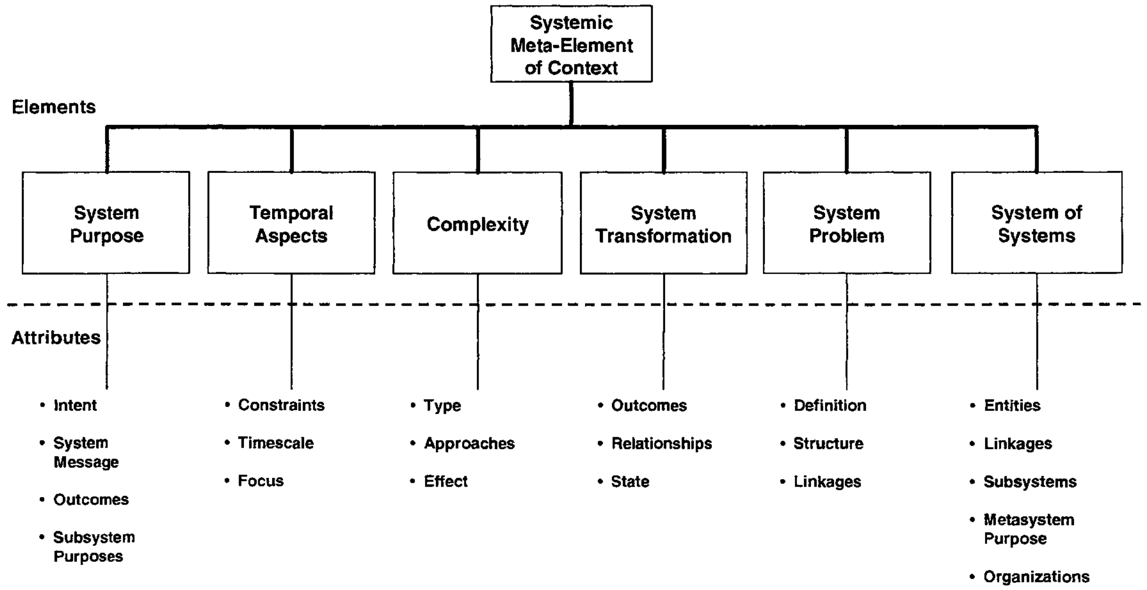


Exhibit 26 above is an illustration of the *Systemic Meta-Element* and their associated attributes. Elements within this major category include: System Purpose; Temporal Aspects; Complexity; System Transformation; System Problem; and Systems of Systems.

*Systemic Meta-Element – System Purpose*

The first element from the Systemic Meta-Element of Context is *System Purpose*. The concept of *System Purpose* was captured as being integral to the ability to articulate system context. *System Purpose* answers questions such as: Why does the system exist? What is the system's mission? What is the system intended to do? Since these questions are all central to what the system looks like, how it is designed, and how it operates, it became clear that *System Purpose* was an important element of complex system context. Accurately describing *System Purpose* is accomplished through four attributes: Intent, System Message, Outcome, and Subsystem Purpose. These attributes and their associated dimensions are shown in Exhibit 27 below.

**Exhibit 27. System Purpose – Attributes and Dimensions**

| Attributes | Dimensions |
|---|---|
| **Intent** | Commonness; Conflict Level |
| **System Message** | Centralization; Alignment; Subsystem Autonomy; System Communication |
| **Outcome** | Alternatives; Desirability |
| **Subsystem Purpose** | Disparity; Meta-system Support; Commitment |

As *System Purpose* further developed as an element of complex system context, it became clear that *Intent* was one aspect of *System Purpose* that must be articulated. The concept of *Intent* is further characterized by two dimensions. The first focused on specifically looking at whether there is a common or shared understanding of the purpose of the system and how strong that common understanding is (Commonness). The second dimension addresses the degree to which different understandings of that intended purpose are either in agreement or conflicted with one another (Conflict Level). These two dimensions, Commonness and Conflict Level, are used to bound the concept of *Intent.*

Another attribute that emerged as fundamental to the element of *System Purpose* was the concept of *System Message* or the mechanism through which the purpose was caused to permeate throughout the system. A total of four dimensions were identified to characterize and specify the attribute of *System Message* (Centralization, Alignment, Subsystem Autonomy, and Intra-system Communication). The dimension referred to as Centralization is a determination of where the *System Message* attribute falls between the two extremes of a centralized or a decentralized approach to dissemination of the purpose within the system. The dimension Alignment provides an assessment or measurement, although qualitative in nature, of the extent to which the purposes of the entities and/or subsystems that make up the system of interest are in line with the overarching purpose, or how much the actions of those the entities and/or subsystems support attainment of the system purpose. Related to, but separate and distinct from the concept of the dimension of Alignment is Subsystem Autonomy. This dimension of the attribute *System Message* pertains to the amount of freedom or independence of action demonstrated by the subsystems within the system of interest. The dimension Intra-system Communications is an indicator of the overall effectiveness of the ability of the system to communicate the message to all entities and subsystems within the system of interest. The next attribute to be discussed is *Outcome*.

The outcomes associated with any system are inextricably connected to the concept of *System Purpose* as an element of system context. As such, it is logical that *Outcome* was identified during the analysis as one of the attributes of *System Purpose*. The attribute *Outcome* refers to the connection between the system purpose and the resultant effect or effects from the functioning of the system of interest. Two dimensions were identified to characterize *Outcome*: Alternatives and Desirability. The dimension Alternatives is an indication of the range of possible outcomes that may precipitate from the system based on its indicated purpose. Desirability refers to the degree to which the system purpose clearly articulates the relative desirability of alternative outcomes.

The last attribute of the contextual element *System Purpose* to be discussed is *Subsystem Purpose*. This attribute acknowledges the fact that complex systems are usually systems of systems, and that each of the subsystems is an integral entity in its own right. Those subsystems may or may not have clearly articulated purposes that either support or conflict with the system purpose of the system of interest. The attribute *Subsystem Purpose* was further characterized by the following dimensions: Disparity, Meta-system Support, and Commitment. Disparity is a dimension that indicates the amount of similarity or dissimilarity among the purposes of the various subsystems, regardless of the subsystems' specific individual purposes. Meta-system Support is a measure of the extent to which each of the associated subsystem purpose either does or does not contribute, in some way, to the purpose of the meta-system or system of interest. The last dimension of *Subsystem Purpose* is Commitment. This dimension is an assessment of the amount of commitment the various subsystems have in supporting the overarching meta-system purpose. In other words, where does the source of subsystem support fall along a range between commitment (intending to support) and compliance (being compelled or obliged support).

*Systemic Meta-Element – Temporal Aspects*

The Systemic Element of Context designated by the term *Temporal Aspects* refers to those aspects of the complex system that are associated with or related to time. The importance of understanding and capturing the time-related facets of complex systems emerged as a significant element of context. The element *Temporal Aspects* includes consideration of time constraints or limits placed on the system, as well as the how different temporal focus (past, present, future) impact the system. The attributes that characterize *Temporal Aspects* are: Constraints, Timescale, Span/Duration, Period of Focus, and State. Exhibit 28 below lists these attributes of *Temporal Aspects* and their associated dimensions.

**Exhibit 28. Temporal Aspects – Attributes and Dimensions**

| Attributes | Dimensions |
|---|---|
| **Constraints** | Flexibility; Decision Points |
| **Timescale** | Range; Span/Duration |
| **Period of Focus** | Past; Present; Future |
| **State** | Past; Present; Future |

Many of the limitations or constraints on a system are related to time – delivery deadlines, periodicity of recurring requirements, etc. The first attribute of the element

*Temporal Aspects* to be discussed, *Constraints*, is intended to capture this part of complex system context. There are two dimensions of *Constraints* that help characterize this attribute: Flexibility and Decision Points. Flexibility is a dimension that provides an assessment or a measurement of how adaptable or open to change any given constraint is. Knowing whether constraints are rigid or more accommodating is critical to understanding complex systems. Decision Points as a dimension of the attribute of Constraints emerged as a way of articulating one specific type of constraint. This dimension captures the existence of, number of, and timing of key decisions that must be either made by the system (internal) or supported by some output of the system (external).

Another system aspect related to time has to do with what frame of reference the system has for time. This characteristic of the Systemic Element of Context *Temporal Aspects* is captured in the attribute *Timescale*. The first dimension of *Timescale* has to do with whether the system deals in the short- or long-range from a time perspective. Does the system function with a near-term or long-term view? Whether the system exists to perform a planning function or to produce a specific output, there are significant differences based on where the system falls along this dimension of *Timescale* called Range. The other dimension of this attribute is Span/Duration, which provides an indication of the duration of activities within the system. For example whether the context within which the system operates consists of processes or functions that occur over a period of years, or weeks, or minutes makes a notable difference in what the system looks like and how it operates. Both of these dimensions of the attribute *Timescale* are crucial in defining and understanding system context.

The final attribute of *Temporal Aspects* is *Focus*, which is an indication of where (from a time perspective) the system and its efforts are concentrated. For example, there are substantive differences in what a system that is focused on things of the future might look like as opposed to a system primarily focused on the present. There are two dimensions used to characterize *Focus*: Period and State. Period is a determination of where along the timeline the Focus is concentrated, while State represents to what extent the system is focused on or cognizant of different time-states (e.g., current-state versus future-state).

*Systemic Meta-Element – Complexity*

The significance of the concept of complexity was stressed earlier in Chapter II, but including *Complexity* as one of the elements within the Systemic Meta-Element of complex system context is based on its repeatedly being highlighted during the interview process as a major concern to those working and researching in the systems domain. In this sense, the discussion of complexity moves away from the theoretical into the system as observed by the systems expert. As a contextual element, *Complexity* considers the degree of complexity, the ways in which the system is considered complex and the source(s) of the complexity. It is also concerned with how the system deals with the complexity and what effect the level of complexity has on the system. The element *Complexity* is further characterized by three attributes: *Type*, *Response*, and *Effect*. These attributes are shown in Exhibit 29 below along with their associated dimensions.

**Exhibit 29. Complexity – Attributes and Dimensions**

| Attributes | Dimensions |
|---|---|
| **Type** | Level; Sources |
| **Response** | Optimality; Adequacy; |
| **Effect** | Views; Uncertainty; Risk |

The contextual element *Complexity* is first modified by the attribute *Type*, which is focused on characterizing system context by assessing the nature of the complexity. This attribute provides an indication of the degree or extent of complexity the system exhibits, e.g., low-complexity to high-complexity. This aspect of *Type* is captured in the dimension, Level. *Type* is also characterized by the dimension Sources, which considers the primary drivers or causes of the system's complexity. For example, complexity could stem from the size of the system and number of entities or subsystems, or from the non-linearity of the systems inherent processes.

The second attribute of *Complexity* is referred to as *Response*, which looks at the system's recognition of complexity and the way in which the system intends or attempts to deal with it or mitigate the impact of complexity on the system of interest in dealing with the complex system problem at hand. There are two dimensions identified to characterize the attribute *Response*: Optimality and Adequacy. Optimality is a measure of the extent to which the system (or the decision-makers within the system) attempts or desires to achieve optimization of the system. The analysis showed that the system's perception of optimization as a primary or principal objective within the complex system was a factor in the complex system context. A related concept is the second dimension of *Response*, Adequacy, which is an assessment of the extent to which the system considers that it is performing or operating adequately.

The final attribute of the contextual Element *Complexity* is *Effect*, which looks at several of the important ways in which complexity affects the system. *Effect* is characterized by three complexity-related aspects described by the dimensions Views, Uncertainty, and Risk. The dimension Views represents the extent to which there are multiple points of view or perspectives of the complex system or complex system problem of interest. The analysis showed that this situation of multiple viewpoints (see discussion in Chapter II on complementarity) is a factor that must be considered in system context. As a dimension of *Effect*, Views captures a quantification of the perspectives and a measure of the degree to which they vary. The remaining two dimensions of Effect, Uncertainty and Risk, though related are still separate and distinct. Uncertainty is an assessment of the degree to which the system is affected by the unknown aspects of the complex system itself and/or its environment. The importance of articulating uncertainty as part of understanding complex system context emerged repeatedly during the analysis. The systems experts were almost unanimous in the importance of capturing uncertainty. While developing a quantitative measure of uncertainty is challenging, developing a qualitative assessment of uncertainty and its affect on the system is what this dimension does. The final dimension of *Effect* is Risk. This dimension is a measure of the number and significance of the risks to which the complex system is exposed or subjected. As indicated earlier, Uncertainty is a related concept and can be one source of risk to the system of interest, but the dimension Risk is a consideration of risks as a composite assessment.

*Systemic Meta-Element – System Transformation*

The decision to include *System Transformation* in the *Systemic Meta-Element* of complex system context came about as the transformational concepts related to complex systems emerged from the analysis as a very strong recurring theme. All of the complex systems of interest discussed in the interviews were either in the midst of transformation or were the planned target of some transformation initiative. That being the case, as the research progressed it became clear that transformation was an integral part of the context of complex systems. The three attributes (*Outcome*, *Relationship Effects*, and *State*) identified to describe the *Systemic Element* called *System Transformation* and the dimensions associated with each of them are listed below in Exhibit 30.

**Exhibit 30. System Transformation – Attributes and Dimensions**

| Attributes | Dimensions |
| --- | --- |
| **Outcome** | Desired; Unintended; Adverse |
| **Relationship Effects** | Intra-system; Inter-system; Inter-subsystem |
| **State** | As-designed; Actual/Current; Desired/Future |

The first attribute that emerged from the analysis of the data associated with the element of *System Transformation* was *Outcome.* This attribute refers to the resultant situation that exists due to the outputs of the system and the influences it has due to external relationships with other systems and its environment. While outputs are usually associated with some tangible, deliverable product or service, outcomes are more of a subjective assessment of the overall contribution or value added by the system. In particular when considering *System Transformation* it was clear that there were several aspects of transformations that should be captured in the attribute *Outcome*. This was done by developing three dimensions for this attribute: Desired, Unintended, and Adverse. The first dimension, Desired, characterizes the degree to which the system (or some agent of system transformation) is able to identify and articulate the objective desired outcome of the transformation of the system. The other two dimensions, Unintended and Adverse, provide a means to capture the extent to which the system is able to identify unintended or adverse outcomes (respectively – adverse is often a specific subset of unintended) and also the impact of these outcomes on the complex system of interest.

The attribute referred to as *Relationship Effects* provides an assessment of the impact or effect of different relationships on the feasibility of system transformation taking place, and also of the impact or effect of transformation on these same relationships. The three dimensions of this attribute consider these effects in three separate categories of relationships: Intra-system, Inter-system, and Inter-subsystem. Intra-system considers those relationships between or among various elements or entities integral to the system. Inter-system considers those relationships between or among the system of interest and other systems with which it is connected or associated. Inter-subsystem takes a system of systems view and considers those relationships between or among the systems that compose the complex system of interest.

The third and final attribute that emerged from the analysis of the contextual element *System Transformation* is *State*. *State* is a measure of three primary aspects of system state: 1) the ability of the system to clearly articulate a single, commonly agreed upon description of different states of the system (As-designed, Actual/Current, and

Desired/Future); 2) its ability to compare and contrast these states and communicate the differences between them; and 3) its ability to develop or design a transformation function from the current state to the desired future state.

*Systemic Meta-Element – System Problem*

While many sections in this chapter make reference to 'complex system problems,' this discussion of *System Problem* within the *Systemic Meta-Element* of complex systems context focuses specifically on that concept. In conducting the analysis, one conceptual thread that was found to run uniformly through the data was the acknowledgment that one or more complex system problems are inextricably linked with the system of interest, and understanding and articulating these problems was integral to being able to understand the system. The analysis yielded three attributes associated with the contextual element *System Problem* namely *Definition*, *Structure*, and *Linkages*. Exhibit 31 below summarizes these attributes of *System Problem* and their associated dimensions.

**Exhibit 31. System Problem – Attributes and Dimensions**

| Attributes | Dimensions |
|---|---|
| **Definition** | Constraints; Metrics; Consensus; Boundary Type; Scope |
| **Structure** | Constructed; Objective |
| **Linkages** | Coupling; Quantity |

*Definition*, the first attribute of *System Problem* to be discussed, focuses on the critical task of identifying, delineating, and characterizing the complex system problem of interest. Five dimensions are identified to elaborate upon the attribute *Definition* and the associated processes. These dimensions (Constraints, Metrics, Consensus, Boundary Type, and Scope) attend to questions such as the following in order to provide the needed illustration of this attribute. Constraints: How is the problem or solution space limited or restricted? How much influence do different stakeholders (PODM, analysts, etc.) have on these limitations? Metrics: What criteria or measure are used to assess or characterize the system problem? What criteria are used to determine whether an entity in inside or outside of the system problem boundary? Consensus: To what degree is there agreement on one common definition of the problem? Boundary Type: How has the boundary of the system problem been established and what are the characteristics (permeability, flexibility) of the boundary as defined? Scope: What is the full extent of the system problem as defined?

The next attribute of *System Problem* is *Structure*, which captures the nature of the complex system problem by categorizing how the concept of the problem was put together. This is done by categorizing the *Structure* within two dimensions: Constructed and Objective. The dimension Constructed provides a measure of the extent to which the structure of the problem was developed through an interpretation of the system and specifics of the problem as conveyed. Objective is a dimension that represents the degree to which the structuring of the problem was influenced by a view of the system and system problem as objective, tangible entities. The balance of these two dimensions captures the attribute referred to as *Structure*.

Lastly, the attribute *Linkages* helps to further characterize the contextual element *System Problem* by considering critical relationships within the system and the system problems. *Linkages* refers to connections between entities, subsystems, and systems associate with the specific complex system problem of concern. It is described or amplified by two dimensions, Coupling and Quantity. The dimension Coupling considers the tightness or looseness of the binding associated with the linkage(s) being considered. It captures whether the connection is flexible or rigid and to what degree variance is accepted or not. Quantity is an assessment of the number of critical linkages within the problem system.

*Systemic Meta-Element – System of Systems*

The final element of context from the *Systemic Meta-Element* is *System of Systems*. As the concept of systems of systems (SoS) emerged from the analysis as being a component of the research focus, it became clear that its significance made it appropriate for being highlighted as one of the elements of complex system context was compelling. The interview data pointed compellingly to SoS as a key piece of the context puzzle. As an element of complex system context, System of Systems takes into account a number of aspects, which are captured in the following four attributes: *Entities*, *System Linkages*, *Subsystems*, and *Metasystem Purpose*. These attributes are shown in Exhibit 32 below along with their associated dimensions.

**Exhibit 32. System of Systems – Attributes and Dimensions**

| Attributes | Dimensions |
|---|---|
| **Entities** | Identifiability; Differentiability; Hierarchy |
| **System Linkages** | System; Metasystem |
| **Subsystems** | Quantity; Complexity |
| **Metasystem Purpose** | Discernability; Subsystem Alignment |

The attribute referred to as *Entities* was the first to emerge from the analysis of the analytical category of data related to the element *System of Systems*. This attributes focuses on the need to be able to understand what all makes up the system of systems (SoS). This begins by discerning what entities or individuals are part of the SoS. The attribute *Entities* is amplified or characterized by three dimensions: Identifiability, Differentiability, and Hierarchy. Identifiability is a representation of the extent to which entities can be identified as being included in the SoS. Related, but separate is the concept of the dimension Differentiability, which captures the ability to distinguish things as being separate and distinct entities within the system of systems. The last dimension of *Entities* has to do with the degree to which there are hierarchical relationships between and among entities within the system of systems.

*System Linkages* is an attribute created to take into account the importance of the relationships within the system of systems. It considers both the links between subsystems within the overarching system of systems or metasystems, and also connections between individual systems the metasystems. The two dimensions of this attribute, System and Metasystem, are measures or assessments of the degree to which critical linkages can and have been identified, and also of the significance of the individual linkages.

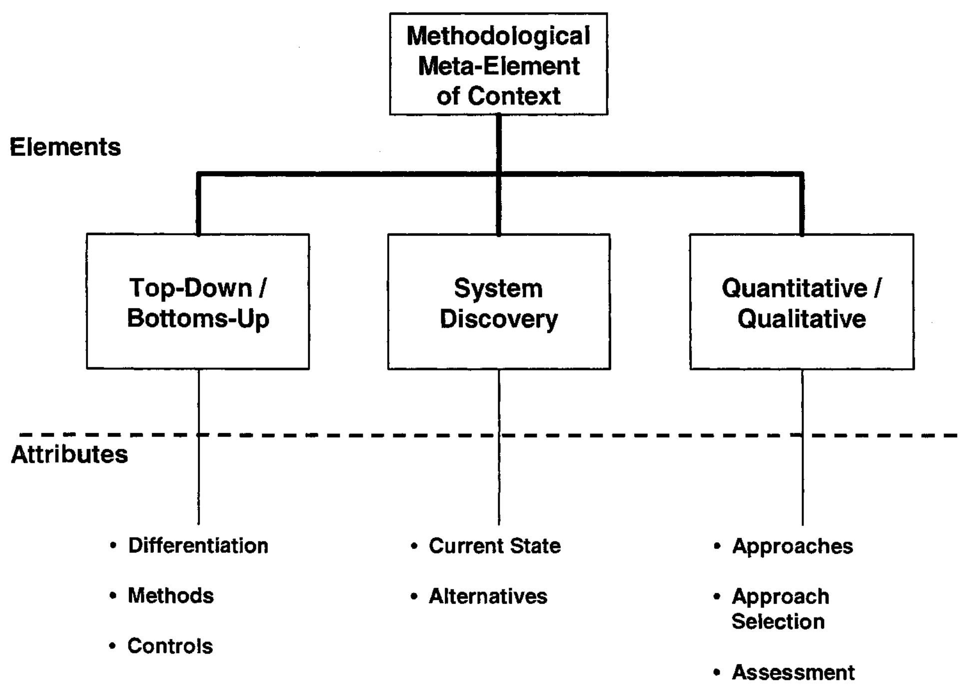
Another essential aspect of SoS that was captured as an attribute of this contextual element was *Subsystems*. By definition, the system of systems is made up of some number of subsystems or included systems that must be included in as part of the discovery process for the SoS. The attribute *Subsystems* provides a means for capturing the scope of the SoS by considering the subsystem level. This is done by articulating two dimensions of this attribute: Quantity and Complexity. Quantity is an evaluation of the number of systems included within the definition of the metasystems. Complexity represents a measure of the complexity of these individual systems.

Just as *System Purpose* was identified as an element of system context, the concept of *Metasystem Purpose* is key to understanding the metasystems under consideration. When applying a SoS view to the system or system problem of interest, there are certain aspects of purpose that must be captured. For *Metasystem Purpose*, the dimensions Discernability and Subsystem Alignment emerged. First, it is essential that they overarching metasystems purpose be understood, therefore Discernability was defined as a dimension to provide a measure of the extent to which the high-level metasystem purpose can be defined, agreed upon, and communicated. Subsystem Alignment is an indicator of the degree of alignment or synchronization of the purposes of individual systems within the SoS with an identified metasystem purpose.

*Detailed Description – Methodological Meta-Element*

The specific systems approaches applied, available, or being considered for dealing with a complex system affect the system, because the approach adopted is integral to system construction and a major determinant of how the system is framed. Therefore, there are aspects of methodology that make up some of the key elements of complex system context. The elements within this top-level category were initially referred to under several different nodes such as 'The Approach' and 'Systems Themes,' which were then merged during continual comparative analysis into a node called 'Methodological Influences.' As the significance of this collective grouping became evident, it was designated as a top-level category or meta-element and entitled the *Methodological Meta-Element of Context* to capture elements related to the aspects of dealing with complex systems that stem from the specific approach or methodology being applied or being considered for application. Exhibit 33 below is a hierarchical representation of the *Methodological Meta-Element of Complex System Context*, showing the elements and those attributes associated with each. The elements in this major category include: Top-down versus Bottom-up; System Questions; Quantitative versus Qualitative; System Discovery; Analysis Tools; and Systems Thinking.

**Exhibit 33. Methodological Meta-Element of Complex System Context**




*Methodological Meta-Element – Top-down versus Bottom-up*

First contextual element to be presented from the *Methodological Meta-Element* is *Top-down versus Bottom-up*. The intent of this element is to capture those approach-based aspects of complex system context that can be delineated as falling at some point between two categorizations of analytical approaches – those that take a top-down perspective of the complex system or complex system problem of interest and those that approach them from a bottom-up perspective. The analysis of the data indicated that the context of the system is notably dependent upon which of these paths may have been adopted over the other, or the balance between the two in cases where a multi-methodological approach is taken. The two attributes (*Differentiation* and *Frameworks*) were identified to describe the *Methodological Element* called *Top-down versus Bottom-up* and the dimensions associated with each of them are listed below in Exhibit 34.

**Exhibit 34. Top-Down versus Bottom-Up – Attributes and Dimensions**

| Attributes | Dimensions |
|---|---|
| **Differentiation** | Level; Granularity; uni-/bi-directional |
| **Frameworks** | Integration/Autonomy; Holism/Reductionism |

The attribute referred to as *Differentiation* emerged from several different discussions from the interview data where various approaches were being discussed. The key concept captured by this attribute is the way in which the actual type or category of approach being taken is delineated or how to discriminate between the types. Three dimensions (Level, Granularity, and uni-/bi-directional) emerged to enable further development of the characterizations captured by this attribute. The dimension, Level, provides an indicator of where within the system a specific approach is being applied. This is particularly relevant when it is desired to be able to draw distinctions among different approaches are being applied within a complex system. Granularity provides an assessment of the level of detail being addressed or analyzed in application of the approach being used. The concept of multi-methodologies leads to the possibility of top-down and bottom-up approaches being joined into some hybrid approach. The dimension, uni-/bi-directional, provides an assessment of the degree to which the approach being used involves one or the other 'directional approaches' or some combination of the two.

*Frameworks* is an attribute of *Top-down versus Bottom-up* that reflects on some of the concepts, tools, techniques, or means employed as part of applying one of or a combination of these approaches. The attribute, *Frameworks*, is further modified through the following dimensions: Integration/Autonomy, and Holism/Reductionism. The first dimension, Integration/Autonomy, provides a demarcation of where the frameworks being applied falls along the continuum between integrating the different processes and approaches being employed and maintaining methodological autonomy of the approach(es) being used. The Holism/Reductionism dimension provides an assessment of the extent to which the frameworks being applied employ or are based in one or the other of these two methodological approaches.

*Methodological Meta-Element – System Discovery*

Another component of the methodological considerations associated with system context is the element entitled *System Discovery*. The view of *System Discovery* as an element of context came to the fore during the analysis as the participants discussed different cases or projects in which they had conducted problem formulation or definition. What emerged was that system discovery is a key methodological segment of all approaches, thereby influencing how the system was defined and perceived. As such, it has a major impact on the context of the system. The element *System Discovery* is further characterized by two attributes, *Current State* and *Alternatives*, which are listed below in Exhibit 35 with their associated dimensions.

**Exhibit 35. System Discovery – Attributes and Dimensions**

| Attributes | Dimensions |
|---|---|
| **Current State** | Problem; Constraints; Modeling |
| **Alternatives** | Desired Future; Unintended Consequences |

*Current State* is the attribute that emerged to capture those aspects of *System Discovery* related to assessing, defining, and articulating the present state of the system. The element *System Discovery* covered a broad spectrum of processes and actions related to learning about the system, but fundamental to the entire concept is accurately capturing the 'as-is' system. The attribute, *Current State*, was further elaborated upon through four dimensions: Problem, Constraints, and Modeling. The dimension, Problem, is a measure of whether and to what extent the system discover process is able to bring to light the 'as-is' state of the complex system problem. The Constraint dimension is a measure of the degree to which constraints were imposed or introduced that hampered the ability of the system discovery process to conduct the necessary 'as-is' assessment or its ability to develop the resultant analysis. Modeling is a dimension that articulates to what degree modeling was used as part of the current state system discovery and what types of models, if any, were developed.

*Alternatives*, the second attribute of *System Discovery*, was established to capture the emergent concepts related to how the system discover process influences and is influenced by considerations of some system state(s) other than the extant state. This attribute is further characterized by three dimensions: Desired Future and Unintended Consequences. The Desired Future dimension provides a way of capturing whether or how extensively system discovery includes considerations of future states, and in particular the desired or preferred objective system state. Unintended Consequences is a dimension of the *Alternatives* attribute focused on the extent to which system discover is aware of and sensitive to potential consequences of system change and even consequences of the system discovery process itself.

*Methodological Meta-Element – Quantitative versus Qualitative*

The next element from the Methodological Meta-Element of Context is *Quantitative versus Qualitative*. The analysis developed strong support for the importance of characterizing where the methodological system context falls along the line between methodologies that are quantitative and those that are qualitative. *Quantitative versus Qualitative* the systems based approaches presented in the data were predominantly qualitative, but most if not all, also included quantitative methods to some degree. This element of context captures the approaches being employed, the manner in which approaches are selected, and the type of assessment the approach is expected to deliver. Capturing this information is achieved by characterizing the *Quantitative versus Qualitative* contextual element through two attributes: *Approaches* and *Assessment*. Exhibit 36 below presents these attributes and their associated dimensions.

**Exhibit 36. Quantitative versus Qualitative – Attributes and Dimensions**

| Attributes | Dimensions |
|---|---|
| **Approaches** | Specific-type; Modeling; Representation; Selection |
| **Assessment** | Uncertainty; Probability; Reliability |

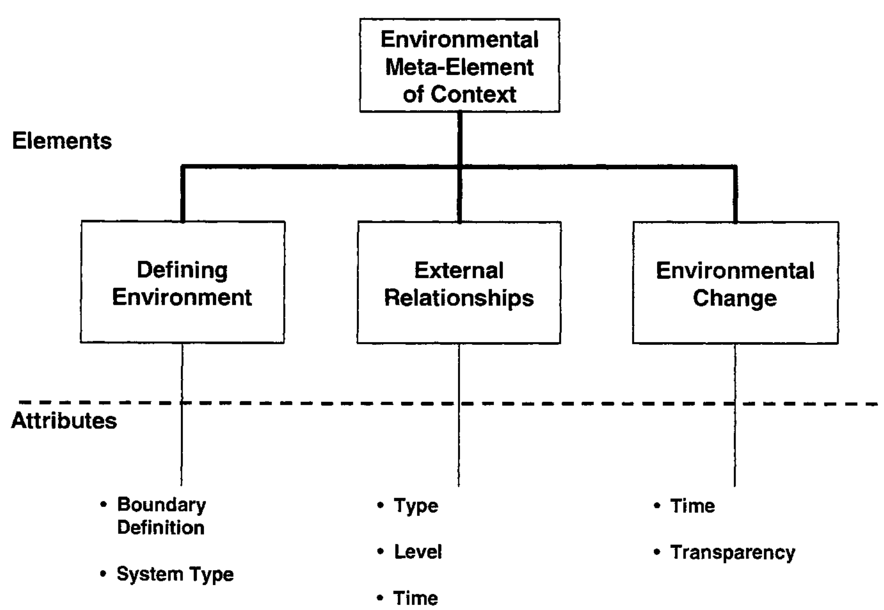
The attribute, *Approaches*, came about when the analysis noted a variety of methodological approaches being used from across the continuum represented by the *Quantitative versus Qualitative* (*QvQ*) contextual element and highlighted the importance within the concept of system context to clearly identify those being employed. This attribute considers the particular approach(es) being used within the complex system engineering/analysis effort; describes the different types of modeling being included; discusses the ways in which the outcomes of the analytical work is represented; and provides the reasoning or justification for the selection of the approach(es) noted. Under the attribute, *Approaches*, these characteristics are described by four dimensions respectively: Specific-type, Modeling, Representation, and Selection.

*Assessment* is an attribute established to represent several of the key issues regarding the application of various methodologies from the QvQ spectrum. Specifically, *Assessment* considers what the stakeholders expect the analysis to provide with regard to assessment of uncertainty, probability, and/or reliability. The research identified that significant problems can occur when there is a mismatch between the assessment expectations and the capabilities of the approach. Three dimensions (uncertainty, probability, and reliability) are used to further articulate the *Assessment* attribute.

*Detailed Description – Environmental Meta-Element*

The discussion in Chapter II regarding system environment being an important aspect of systems thinking was reinforced and expanded in the course of analyzing the data. Very early in the analysis, it became apparent that there were elements of context related to environment. Initially a basic category entitled 'The Environment' was created to capture the aspects of dealing with complex systems and understanding complex system context that are related to the system's environment. After several related categories (e.g., concerning 'external relationships' and 'external changes') were merged into it, 'The Environment' became 'Environmental Influences,' and then finally emerged as the *Environmental Meta-Element of Context.* The elements of context that emerged under this major category are: Defining Environment, External Relationships, Influences, and Environmental Change. Exhibit 37 below is a hierarchical

**Exhibit 37. Environmental Meta-Element of Complex System Context**



representation of the *Environmental Meta-Element of Complex System Context*, showing the elements and those attributes associated with each.

*Environmental Meta-Element – Defining Environment*

*Defining Environment* is the first contextual element to be presented from the *Environmental Meta-Element.* The first matter that must be established in attempting to analyze the contextual implications of systems environment is how the system's environment is defined. In the case of complex systems and systems of systems, this determination is frequently not readily comprehensible or transparent. What is required is not simply a matter of providing a textbook definition of environment, but rather the articulation of the system-specific criteria utilized to delineate or demarcate the environment. Doing so requires development of a consistent approach for determining what is and what is not part of the system. The element, *Defining Environment*, is described through two attributes: *Boundary Definition* and *Boundary Properties*. These attributes and the dimensions associated with each of them are shown in Exhibit 38 below.

**Exhibit 38. Defining Environment – Attributes and Dimensions**

| Attributes | Dimensions |
|---|---|
| **Boundary Definition** | Selection Criteria; Stakeholder Boundary Perspective |
| **Boundary Properties** | Permeability; Elasticity; Permanence |

*Boundary Definition* is the attribute established to explicate the manner in which the system's boundary is determined or defined. To do this, the *Boundary Definition* attribute needs to establish initially what criteria are used or applied to 'things' (systems, individual entities, etc.) to ascertain which side of the boundary they should be on. This 'inside/outside' selection process is what defines the environment. The attribute also considers several characteristics of the boundary and the way stakeholders view the system boundary. The first dimension of *Boundary Definition* is Selection Criteria, which provides a detailing of the specific guidelines used to establish exactly where the boundary should fall by determining whether any given item is or is not part of the system at a given time. These criteria will normally evolve as the system evolves and as understanding of the system is further elucidated through discovery. Stakeholder Boundary Perspective is a dimension established to capture the extent to which a shared view of the definition of the system's boundary exists among system stakeholders.

The second attribute of *Defining Environment* is *Boundary Properties*, which is established to account for the concept that emerged from the analysis that system boundaries exhibit different characteristics and qualities thereby contributing to the need to capture this as part of the system-specific context being articulated. Three facets of system boundaries emerged during the analysis as characteristics that should be included as part of developing system context. These concepts are captured in the dimensions of Permeability, Elasticity, and Permanence. Permeability is an indication of the degree to which interactions, information, products, etc. are able to cross the system boundary in one direction or the other. Elasticity represents the characteristic that system boundaries exhibit whereby the boundary expands or contracts over time in response to changes in the system, the environment, or other aspects of the system's context. Lastly, Permanence provides a determination of the anticipated lifespan of the boundary, noting that some systems are long-term in nature and others are more transient.

*Environmental Meta-Element – External Relationships*

*External Relationships*, as a contextual element, emerged from several discussion threads in the interview data that stress the importance of relationships the complex system has with other systems or entities outside of the system. The concept of context that developed during the data analysis includes these relationships as key elements of the system's context. *External Relationships* as defined in this instance refers to any and all connections or linkages between the system of interest and any other entity, including relationships that occur at the metasystem level, subsystem level, or component/entity level as long as there is a tie to something that lies outside of the system, in other words the link crosses the system boundary. Three attributes were identified in association with this element of context: *Type*, *Level*, and *Time*. Exhibit 39 below shows the attributes and associated dimensions of the element *External Relationships*.

**Exhibit 39. External Relationships – Attributes and Dimensions**

| Attributes | Dimensions |
|---|---|
| **Type** | Direction; Objects; Coupling |
| **Level** | System; Subsystem; Entity; Cross-level |
| **Time** | Time Period; Range |

The first attribute of *External Relationships* to be presented is *Type*, which provides a means of categorizing or classifying the external relationships being analyzed. This attribute takes into account whether the relationship is one-way (inside-out or outside-in) or two-way, captured by the dimension Direction; what parts of the system are 'parties' to the relationship, captured by the dimension Objects; and what degree of linkage (tight or loose) is involved in the relationship, captured by the dimension Coupling.

*Level* is an attribute established to articulate where within the system the relationship originates or terminates. External relationships can occur at the macro level, originating from the metasystem perspective or they can be linked to any of the subordinate levels within the metasystem. *Level* is another aspect of external relationships that emerged as being significant in articulating the element of context *External Relationships*. Four dimensions (System, Subsystem, Entity, and Cross-level) were created to characterize *Level*. The first three identify a specific system level where the relationship is instantiated, and the fourth capturing those instances where a given relationship involves multiple levels from within the system.

The final attribute for this element is *Time*, which captures two key aspects identified during the analysis. *Time* refers to the periodicity of interactions associated with the relationship and also the span of time over which the relationship does or is expected to exist. These facets of the attribute *Time* are delineated through two dimensions: Period and Range.

*Environmental Meta-Element – Environmental Change*

As the concepts related to complex system environment emerged during the analysis and a recurring theme developed related to change within the environment, it was determined that *Environmental Change* needed to be included as one of the elements of complex system context within the *Environmental Meta-Element.* In analyzing the data from the interviews, the importance of the system having awareness of and being able to respond to environmental change was highlighted throughout. With that foundation in the data, *Environmental Change* was definitely integral to the concept of context of complex systems. Two attributes (*Time* and *Transparency*) were identified to describe this *Environmental Element.* These attributes and the dimensions associated with each of them are listed below in Exhibit 40.

**Exhibit 40. Environmental Change – Attributes and Dimensions**

| Attributes | Dimensions |
|---|---|
| **Time** | Rate; Period |
| **Transparency** | Cause/Effect; Predictability |

The attribute of *Environmental Change* referred to as *Time* is established to capture the temporal aspects change as it occurs within the environment, with two key facets of change being considered in this attribute. First of all, the analysis illustrated that the rate at which change occurs within the environment was a major factor on the influence environmental change has on the system of interest. Some systems exist in changes are conceived and implemented very rapidly, while in other instances change is more deliberate and implementation is planned over an extended timeframe. The other temporal facet of change is the periodicity of change. Some environments experience changes occurring one after the other virtually non-stop, while in other situations changes are much rarer. The two dimensions of this attribute, Rate and Period, capture these facets respectively.

One aspect of change in the environment that emerged as an essential component of the concept of this element of context was the ability of the system to have visibility of these changes. This aspect is captured in the second attribute of *Environmental Change*, *Transparency*, which is further characterized through two dimensions, Cause/Effect, and Predictability. Cause/Effect provides an assessment of the degree to which the system of interest has understanding of the cause/effect relationships associated with changes happening or impending within its environment. The second dimension of *Transparency* is Predictability, which is a measure of how capable the system is of forecasting changes before they occur and being able to plan for them.

Detailed Results – Summary

This section provided a detailed breakdown of the four meta-elements of complex system context, with the discussion of each including a comprehensive description of each of the individual elements of context within the meta-element, a detailed accounting of the attributes that emerged to provide elaboration of the key facets of the elements, and a listing and description of the dimensions of those attributes. These results, in and of themselves, have made a significant contribution to the system body of knowledge, because they provide a far greater level of granularity in describing the concept of complex system context, which is based on rigorous research and firmly grounded in data. Following the grounded theory method, these analysis results provided the key input to the beginning of the final phase of the method, theory development. The next section discusses the theory construction process and then presents the grounded theory of complex system context.

## THEORY CONSTRUCTION

This section discusses the results of the final phase of the grounded theory method, where the detailed results of the previous coding and categorization are synthesized and distilled to produce the theoretical construct that was the objective of the Research Questions:

1. ***What are the constituent elements of complex system context, and what attributes and dimensions characterize these elements?***
2. ***What systems-based framework can be developed for constructing and articulating complex system context?***

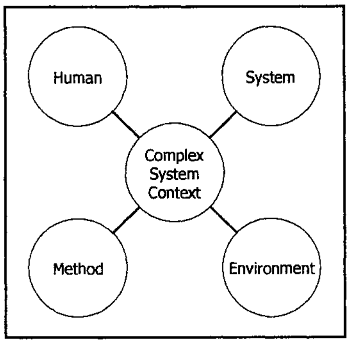
The discussion in the preceding section provided the details of the results of open, axial, and selective coding as part of the grounded theory method. The resultant categories and relationships were then integrated into a grounded theory, the single theoretical statement or series of statements that are the desired outcome of the grounded theory method.

As discussed in Chapter IV, in accordance with the grounded theory method, in order to move from selective coding into theory development, the 'storyline' must be develop, capturing or establishing the major themes, concepts, and constructs that had emerged from the analysis and describing the phenomenon of interest, complex system context. The following section covers this storyline development.

*Major Themes and the Storyline*

The first major concept that emerged from the analysis was that complex system context is a construction through which the four top-level groupings of contextual elements, or meta-elements, (Human, Systemic, Methodological, and Environmental) were established. These meta-elements, the keystones for developing the theory of complex system context, are represented in the Meta-Element model shown in Exhibit 41.

**Exhibit 41. The Meta-Element Model of Complex System Context**

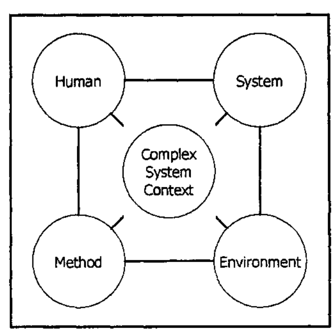



Under each of these meta-elements are a number of basic elements of context, each of which is characterized by a specific set of attributes and dimensions. These combine in a nearly infinite number of combinations to produce each system's unique, system-specific context. While no two system contexts are exactly alike, using the elements of context it is possible to establish similarities and differences between and among the contexts of different systems.

Another aspect that emerged from the analysis is that while all four of the meta-elements are related to complex system context, there are also strong relationships between the different high-level elements, as well as among their subordinate elements.

These interrelationships emerged as significant during the analysis of the individual elements. Appendix K provides an example of data analysis results illustrating the intersections, or interconnectedness of one specific set of elements. The importance of this in understanding complex system context cannot be overemphasized, for it is essential to understand that changes in elements in one area (e.g., Human Meta-Element) can have significant implications within one of the other areas (e.g., Systemic Meta-Element or Methodological Meta-Element), and consequently have a tremendous impact on the Complex System Context. Exhibit 42 below illustrates these relationships in the construction of complex system context.

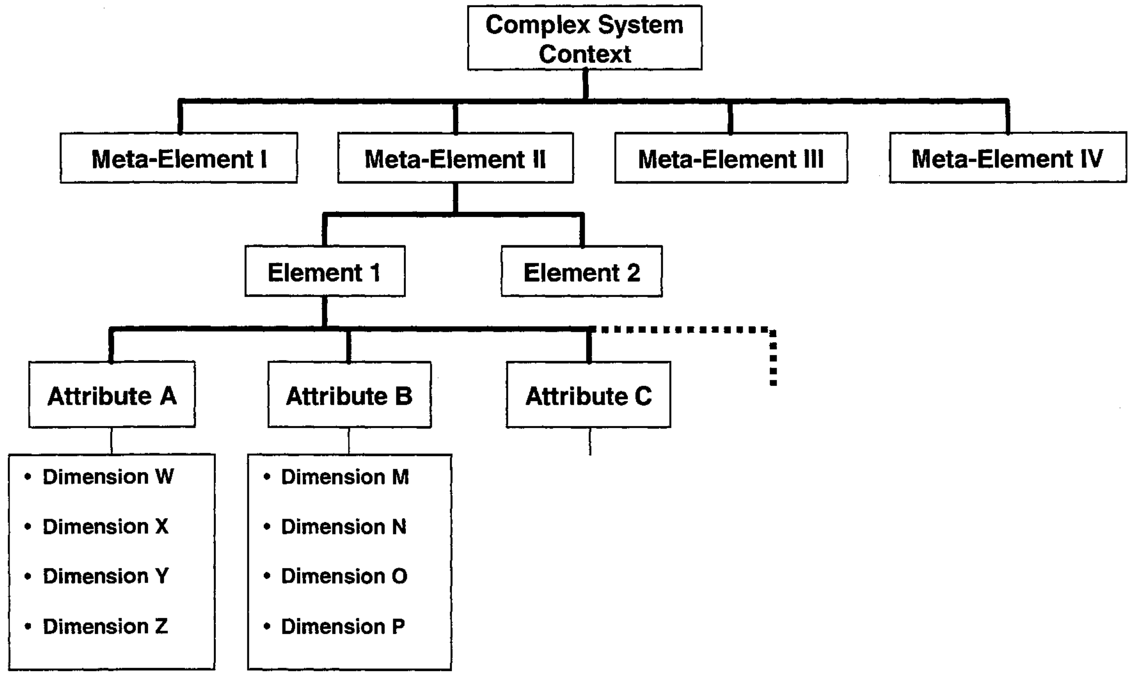
**Exhibit 42. Meta-Element Model Showing Interrelationships**




Having established the meta-elements and their subordinate elements (discussed in detail earlier), and understanding the relationships among them and their subordinate elements, it was possible to construct the grounded theory storyline to support theory development.

The storyline is based heavily on relationships. Exhibit 43 illustrates the hierarchical structure of the elements of complex system context. This illustration

**Exhibit 43. Hierarchy of Meta-Element – Element – Attribute – Dimension**




points out that dimensions characterize a given attribute, which then collectively characterize a given element. The elements collectively characterize the meta-elements. While it is important to acknowledge that each element is independent and distinct in and of itself, this hierarchy of relationships is integral to understanding the story of complex system context. As discussed in Chapter II, the consensus in the literature is that understanding and appreciating complex system context is an integral part of defining or architecting a new complex system, modifying or transforming an existing one, or attempting to wrestle with one of the messy complex system problems facing society today. This illustration of the hierarchical relationships is not intended to suggest that it is possible to derive some single measure or metric of complex system context. The importance of the structure portrayed above is that when considering complex system context, one must gain an appreciation for all of the underlying building blocks.

Another major theme that emerged from the data is that each dimension defines some set of values (whether qualitative or quantitative) either as a range along some continuum, or as a set of discreet values (perhaps even a simple binary range), or as a scale of some sort; and that for each dimension an assessment can be made to determine where that specific dimension lies within that set of values. From this, given a specific complex system, it is possible to assess each of the elements of complex system context and determine the value for each of its dimensions. Collectively, this assessment across all elements, attributes, and dimensions provides a view or perspective of the system-specific context for that particular complex system.

Along with the concept of meta-elements and interrelationships, the concept of assessment of complex system context at a dimensional level was foundational in carrying out the theory development phase of the grounded theory method. These concepts capture the major themes that emerged from the data during the analysis, allowing them to be tied together into a single storyline that describes how the phenomenon called complex system context was conceptualized. The next section presents the grounded theory of complex system context, which is based upon these major themes and the resultant storyline.

*Grounded Theory of Complex System Context*

In developing the grounded theory of complex system context, the intent was to capture all of the significance and richness of the analytical results of this research in a single statement or qualitative model that represents complex system context, the elements of context as they emerged from the analysis, and the significant relationships among them.

The qualitative model of the theory of complex system context is represented in following statement:

> ***Complex System Context can be established as a classification with respect to four Meta-Elements: Human, Systemic, Methodological, and Environmental. These Meta-Elements, and their interrelationships, provide a framework for construction of context for a complex system.***

As discussed in the preceding section, Meta-Element assessments are the collective valuation of the elements associated with each Meta-Element, and the assessment of each element is based on the assessments the all associated attributes as characterized by the dimensions related to each attribute.

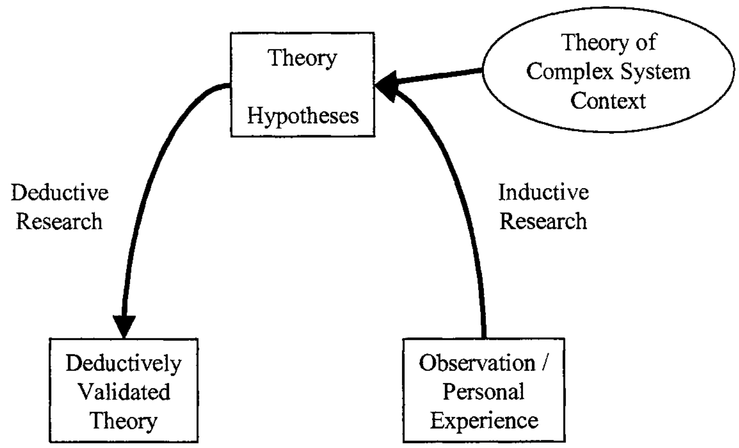
The grounded theory of complex system context, represented by this qualitative model and the Meta-Element Model (Exhibits 41 and 42), encapsulates the outcome of the research and provide the definition of complex system context that served as the underpinning for the development of the Complex System Contextual Framework (CSCF).

*Empirical Testing and Validation*

This section presents a possible way ahead for getting to a point where the grounded theory of complex system context can be empirically tested. Considering that the grounded theory method is an inductive form of research, one of the most important outcomes from grounded theory research is the development of valid theories or theoretical constructs. When appropriate, these theories can form the basis for research using empirical methods of validation.

Exhibit 44 depicts the Inductive – Deductive Research Cycle, and shows the progression of the grounded theory of complex system context as it was developed, at present having reached the point where consideration of application of deductive methods of analysis and/or testing could be considered. In line with the full intent of the grounded theory method, this theory or theoretical construct has reached the position along Weick's (1995) 'theorizing' continuum of being a validate theory through the validation provided within the grounded theory method. That said, as the theory is advanced to a position to appropriately consider deductive methods, additional development may be considered. For example, given that a system-specific assessment of complex system context is feasible, additional research needs to be conducted to actually establish the range of possible values (or levels, or metrics) for each of the dimensions associated with the elements of complex system context. Once these have been established, it will be possible to conduct specific deductive research to empirically test the theory of complex system context.

**Exhibit 44. Inductive – Deductive Research Cycle**




While it would have been ideal for this research to have gone to the extent of fully developing the values of the dimensions, given the methodology employed, the resultant focus of the data collection, and the primary intent of the research - to identify the elements, attributes, and dimensions of complex system context - it was not feasible to do this and remain grounded in the data. Trying to stretch the analysis to address this need would have seriously detracted from the credibility of the research.

This section discussed the construction of the grounded theory of complex system context. The next section will address the development of the Complex System Contextual Framework (CSCF).

## COMPLEX SYSTEM CONTEXTUAL FRAMEWORK (CSCF)

In developing the Complex System Contextual Framework (CSCF), the goal was to create a means of capturing the detailed results presented above in a compendium that could be used as the basis for development of methods or methodologies for articulation of context. It was important that the CSCF include all of the components of the detailed analysis, but in a vehicle that would be viable in a variety of applications.

The CSCF, as constructed, presents the entire hierarchy of complex system context, Meta-Elements – Elements – Attributes – Dimensions, as discussed in this chapter. However, this extensive structure is condensed into a single document that provides an intuitive layout of the elements of complex system context and their relationships. However, as discussed earlier, additional work must be done in developing the levels or metrics of the dimensions defined for the elements of context.

Exhibit 45 below provides an excerpt of the CSCF, specifically the element *Problem Owner/Decision-Maker*. The complete CSCF is introduced in Appendix L.

**Exhibit 45. Excerpt from the Complex System Contextual Framework**

| Element | Attribute | Dimension | Value/Assessment |
|---|---|---|---|
| Problem Owner/Decision-maker | Identity/Authority | Identification | |
| | | Number | |
| | | Process | |
| | | Designation | |
| | | Resource Control | |
| | Knowledge/ Experience | Domain Knowledge | |
| | | Systems Knowledge | |
| | | Decision-making Experience | |
| | Problem Concept | Expectations | |
| | | Concept Flexibility | |
| | | Constraints/Limitations | |
| | | Objectives | |
| | Relationships | Stakeholder Relationships | |
| | | Direct Support Roles | |

**CHAPTER SUMMARY**

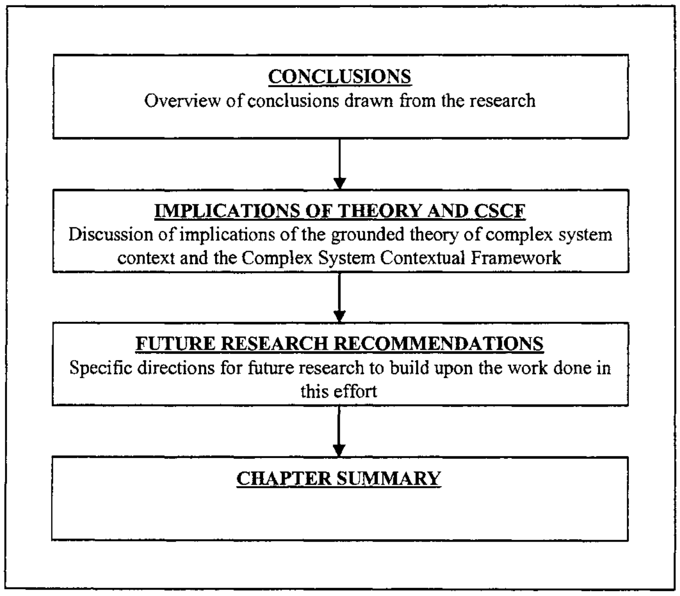
This chapter presented the results of the qualitative analysis conducted in this research using the grounded theory method. A description of the semi-structured interviews was provided and then a high-level view of the results of the analysis of the data. Then each of the key concepts or themes that emerged during the analysis was presented discussed in detail and its 'fit' into the overall theoretical construct was clarified. The chapter concludes with presentation of a grounded theory of complex system context (the integrated model of the Meta-Element Model and the qualitative model for Complex System Context); and finally introduction of the Complex System Contextual Framework (CSCF). Chapter VI provides conclusions and interpretations from the research.

# CHAPTER VI

# CONCLUSIONS AND INTERPRETATIONS

Chapter V presented the results of the detailed analysis performed utilizing the grounded theory research methodology developed for this research, proposed the integrated model representing the constructed grounded theory of complex system context, and introduced the Complex System Contextual Framework. This chapter provides a discussion of the conclusions drawn from this research, implications of the constructed theory and the Complex System Contextual Framework (CSCF), and recommendations for future research directions in support of further developing of the theory of complex system context and elaborating upon the CSCF. Exhibit 46 is a graphical representation of the layout of Chapter VI, illustrating the organization and flow of the discussion of research conclusions and interpretations.

**Exhibit 46. Chapter VI Layout Diagram**



## RESEARCH CONCLUSIONS

This section discusses the overarching conclusions drawn from the research. As presented in Chapter II, the literature made it clear that understanding complex system context was an essential part of the analysis of any complex system or complex system problem. This identified the concept of system context as a shortcoming or gap in the systems body of knowledge, because it lacked consistency and clarity of meaning and because no structured approach was available to articulate context for a given complex system. This research was initiated to fill that gap.

### Research Purpose and Research Questions

This presentation of research conclusions will, therefore, begin by recalling the research purpose and research questions identified in Chapter I. In summary, the purpose of the research was to use the grounded theory method to develop a framework for establishing and articulating complex system context within the domain of, and in support of systems-based analysis of complex systems problems. Based on this, the research was specifically focused on answering two research questions:

1. What are the constituent elements of complex system context, and what attributes and dimensions characterize these elements?
2. What systems-based framework can be developed for constructing and articulating complex system context?

The initial issue that must be considered in the conclusions is whether the purpose of the research was met, and whether the research questions were answered. The basic answer is that the research did, in fact, fulfill these requirements, by achieving the following significant research outcomes:

- Identification of the individual elements of complex system context
- Emergence of the concept of the four meta-elements of complex system context
- Discovery of the interrelationships between elements/meta-elements
- Delineation of the attributes and dimensions of the elements of context
- Construction of the theory of complex system context and development of the CSCF

Considering these outcomes, it can be stated that the requirements of the research purpose and research questions were met, and in that sense, the research purpose was supported. These outcomes will be discussed in detail later in this section.

**Research Perspective of Complex System Context**

In addition to presenting how the research addressed the research purpose and research questions, this discussion must consider whether the research supported the research perspective of complex system context (Exhibit 47) introduced in Chapter II.

**Exhibit 47. Research Perspective of Complex System Context**

| **Complex system Context** |
|---|
| Includes events, incidents, factors, settings, or circumstances that in some way act on or interact with the system, perhaps as enabling or constraining factors; |
| Includes an 'enacted' environment (Weick, 1995), which captures system/environment interactions and interdependencies, however, system context and system environment are conceptually distinguishable; |
| Is a construct or interpretation of properties of a system that are necessary to provide meaning to the system, above and beyond what is objectively observable; |
| Is reflexive in nature, resulting in context further defining the system while the elements of the system are part of the self-same context; and |
| Does not have a single true reality or correct interpretation of context, indicating that the principle of complementarity applies equally to system context as to the system itself. |

The results of the research as reported in Chapter V and the significant outcomes discussed above definitely supported the basic concepts conveyed in this research perspective. Considering the perspective preceded the research and was indicative of the philosophical and theoretical leanings of the researcher, it could be argued that no other eventuality should have been expected. However, the perspective was developed solely to bound the scope of the problem and help shape the research design, and there is no indication that it had undue influence on the collection or analysis of data. The next section provides amplification on the outcomes of the research and how they supported the previously recounted research purpose, questions, and perspective.

**Significant Research Outcomes**

The outcomes of the research discussed above are discussed in this section. This presentation provides amplification on these key outcomes and elaborates how the requirements related to the research purpose, research questions, and research perspective were successfully met.

The Meta-Element Model laid the groundwork for the further elaboration of the structure, defining that the elements of context could be captured within the domains of the Human, Systemic, Methodological, and Environmental Meta-Elements. Additionally, it was determined that each of these elements was characterized by some number of attributes that could be evaluated through a set of dimensions; and each dimension defines some range of values or levels, or some other metric that allows an assessment to be made to determine where that specific dimension lies within that set of values. Collectively, this assessment across all elements, attributes, and dimensions of a particular system provides a view or perspective that articulates the system-specific context for that system. The grounded theory method used in the analysis provided the ability for these foundational themes and concepts to manifest themselves through the emergence of clear coding categories and the strong affinities among them. Represented by the qualitative model of complex system context, the grounded theory that was developed encapsulated the outcome of the research, providing the definition of complex system context that served as the underpinning for the development of the CSCF.

The interdependencies among the identified elements of context proved to be a crucial component of the overall concept of complex system context. The conclusion to be drawn is that when considering complex systems and the contexts within which they exist, one must be aware of and sensitive to these relationships, for failure to do so may result in changes to one element of context having unintended and undesired outcomes within another element. The tool used in conducting the grounded theory analysis, N6 (NUD*IST version 6 by QSR), provided a means of showing the relationships among the different elements of context, allowing the concept of their interdependence to surface from the data.

Through this research, it was shown that the concept of complex system context can be delineated using a hierarchy of defined elements, attributes, and dimensions. This hierarchical structure can then be used to analyze and assess the context of a given system of interest, and the results of that analysis can then be articulated in a comprehensive framework that allows for a structured representation of the complex system context for that specific complex system or complex system problem of interest.

The final observation is that the CSCF and the associated theory provide an underpinning and foundation for the concept of complex system context. These constructs are a substantive representation of the concepts of complex system context drawn from the data set used in this research. As discussed in the limitations section of Chapter I, one of the major challenges of this research is the transferability or transportability of this theoretical construct to other complex systems situations. While efforts were taken to maximize the generalizability of the research, it is recognized that follow-on research may suggest additions or modifications within this theoretical basis. That is not only acceptable but also highly desirable, for the intent of this research was to lay the initial groundwork for developing the requisite clarity and visibility on complex system context and its importance in the use of systems-based approaches to complex system problems.

**IMPLICATIONS OF COMPLEX SYSTEM CONTEXT THEORY AND CSCF**

The theory of complex system context developed through this research and presented in Chapter V has several significant and far-reaching implications. For systems knowledge in general, it provides needed clarity and definition to the concept of complex system context. Through grounding in the data and compliance with a rigorous analytical methodology, the research engendered the requisite degree of credibility and establishes validity of the theoretical construct. As a result of this research effort there will be a considerable increase in the depth of meaning of other research and literature concerning systems engineering, systems analysis, or other systems-based approaches, where complex system context has been established as a critical component.

The theory of complex system context will also prove to be indispensable where other research is being conducted on topics such as complex systems, complex system problems, complex adaptive systems, and systems of systems. In many of these domains, there is still a great deal of research ongoing in the area of problem or system definition. The theory of complex system context can contribute greatly in this ongoing work because system context is conceptually central to these discussions.

The Complex System Contextual Framework also has significant implications for systems research. This outline of context puts structure and organization to a concept that previously was nebulous and amorphous. This hierarchical nature of the framework makes is easy to add to or modify, and makes it an ideal 'point of departure' for follow-on research efforts looking at complex systems in general and complex system context specifically. Additionally, the CSCF provides an excellent method for capturing complex system context in order to support the further development of the theory of complex system context.

Another area where the CSCF makes a significant contribution is in the area of systems practice or application. While not in and of itself a tool or methodology that can be taken into the field and applied in addressing complex system problems, the CSCF brings systems professionals one step closer to such a vehicle. With some further work in development of the dimensions, along with the establishment and validation of metrics for each (quantitative or qualitative), the CSCF will deliver an invaluable tool into the hands of a wide range of hands-on practitioners who are working to bring the power of systems-based approaches to bear in the resolution of consequential and substantive real-world problems. Appendix M provides further amplifications of potential contributions of the CSCF toward a variety of practical applications.

Lastly, this research made a significant contribution in the area of research methodologies in engineering management and systems engineering in two areas - by furthering the use of the grounded theory method in this domain and by furthering research in systems-based approaches incorporating a research design based upon a subjective paradigm and a similar worldview of the researcher. The applications of grounded theory method have expanded greatly since its inception going well outside of its original domain of sociology. However it has not shown a strong presence within the engineering or systems fields (particularly engineering management, systems engineering or other systems disciplines). This is possibly because although its originators indicated it can be use with any type of data grounded theory method is most frequently employed as a qualitative approach, and therefore is not regarded by many in these fields as demonstrating sufficient positivistic rigor. The success of this research has demonstrated the application of the grounded theory method in this area and will greatly enhance the future ability to conduct inductive research to address issues germane to engineering management and systems engineering, such as: complexity, decision-making, situated (in situ) processes and relationships, change and change management, individual and group behavior, and other issues of substance to systems-based approaches.

As discussed in the preface and in Chapter III, the paradigm under which this research was conducted definitely fell near the ‘subjectivist’ end of the schema presented in Burrell and Morgan's (1979) Subjective-Objective Dimension. In all aspects (ontologically, epistemologically, methodologically, and in human nature), this research was viewed as an interpretive, constructive endeavor. Again, applying an approach such as this falls outside of the accepted objectivist (positivist, realist) view most frequently applied in this domain. This research pushed the research outside of that normal worldview and in so doing made a significant contribution toward the viewing systems and systems concepts interpretively.

This section presented the major implications and significant contributions of the research. The following section discusses future research directions and recommendations.

## FUTURE RESEARCH RECOMMENDATIONS

One of the roles of rigorous scholarly research is to further research within the domain in question. This section considers the current state of the systems body of knowledge and the systems perspective discussed in Chapters II and III; in combination with the results, conclusions, and implications of this research presented in Chapter V and this chapter. Taken in total, these clearly indicate fertile areas within the systems field for future research. Through the development and articulation of the concept of complex system context, this research provided some substance to bolster the lack of rigorous research in the area defining complex systems and complex system problems. However, there are many areas yet to be addressed by rigorous research, including elaboration of the concept of complex system context and the CSCF and expansion of complex systems/systems of systems perceptions and methodologies.

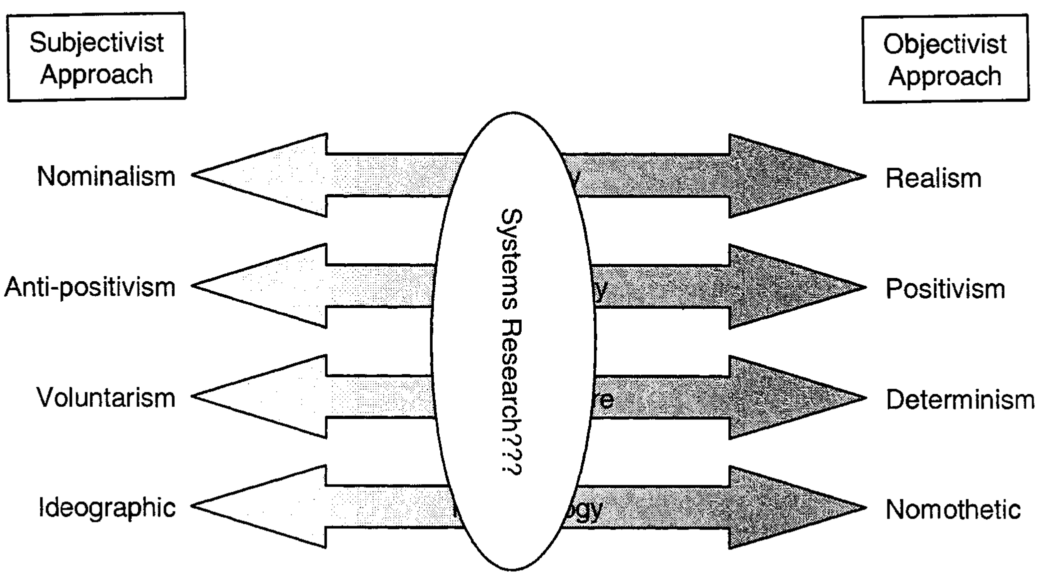
As discussed in detail in Chapter II, there is much need for the development of better ways to understand and deal with complex system problems facing society and the attendant complex systems, which over time, have become more "ill-defined, contextually bound, exceedingly complex, and not well suited to traditional systems engineering approaches" (Keating et al, 2003a). The literature identifies numerous areas within the systems domain where established systems-based approaches have been found to be lacking and additional research is required to further develop the understanding of complex systems and increase effectiveness in dealing with such systems, (Jackson and Keys, 1984; Flood and Carson, 1993; Midgley, 2000; Murthy, 2000; Keating and Sousa-Poza, 2003; Keating et al, 2003b; Warfield, 2003). Although these points were made across a broad spectrum of subject matter (systems engineering, systems of systems, systems science, systemic intervention, complexity, and management), the underlying shortcomings they identified in the systems body of knowledge apply equally to all endeavors within the systems domain that are looking at addressing increasingly complex systems. Drawing upon these issues, the following recommended way ahead is divided into three areas – philosophical issues, theoretical issues, and methodological issues.

**Future Research - Philosophical Issues**

This research presented a systems philosophy that was a product of the paradigm of the researcher and the focus of this research. This area of the research direction is focused on the need to address longstanding philosophical issues in the systems domain.

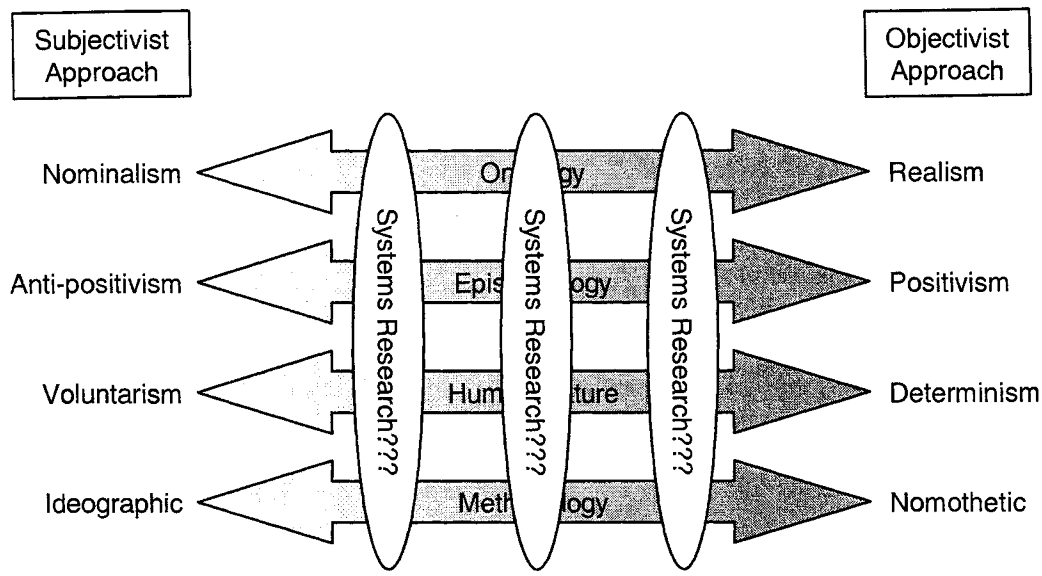
- Can a single systems philosophy be conceived that is sufficiently inclusive to address all aspects within the systems domain? Can (or should) a distinct position be established on Burrell and Morgan's (1979) subjective-objective dimension where systems research should take place (Exhibit 48)?

**Exhibit 48. A Single Systems Philosophy?**




- If there is no such single philosophy, can a series of systems philosophies be defined that capture some appropriately limited range of possible positions along Burrell and Morgan's (1979) subjective-objective dimension (Exhibit 49)?

**Exhibit 49. A Range of Systems Philosophies?**




## Future Research – Theoretical Issues

Much of the discussion in the literature and in the data collected in this research was focused at trying to develop ways to improve complex system performance or how to transform complex systems or systems of systems, yet at the same time, there is a lack of clarity as to what is meant by these lofty aspirations. This area of the research direction is focused on moving from these goals from the conceptual level to the theoretical level, developing frameworks and theoretical constructions that go beyond description and move to defining operative relationships to clearly articulate what these concepts mean. Research must move forward to develop theoretical constructs that establish:

- How is complex system performance defined? What elements of the complex system influence performance? How can these elements be characterized to capture the contribution (positive or negative) to overall system performance?

- How is complex system transformation defined? What parameters can be established for determining the need to transformation? What should be the indicators of system transformation direction? What framework can be developed for articulating a complex system transformation function, a roadmap from the 'as is' system state to some transformed 'to be' state?
- The area of systems of systems (SoS) is emerging as an extension or refinement of complex systems concepts, focusing on buttressing the shortcomings of traditional systems in addressing these increasingly complex systems problems. Theoretical development is required to fully construct the conceptual underpinnings of SoS to firmly establish it and differentiate it from other systems concepts.
- With regard to this research and the resultant grounded theory of complex system context, there is a need to expand upon the present research by applying this approach across a larger sample covering a broader spectrum of disciplines or functional areas. This would expand the basis of the concept of complex system context. Considering the nearly unanimous concurrence that context is such an essential part of understanding complex systems, it is important to build upon the foundation established in this research.
- Another area of the theory of complex system context requiring further development is the need for establishment or definition of the ranges of possible values (or levels, or metrics) for each of the dimensions associated with the elements of complex system context. Once these have been established, it will

be possible to conduct deductive research to empirically test the theory of complex system context.

## Future Research – Methodological Issues

A number of methodological issues were identified over the course of this research. Some of these emerged from the examination of the systems body of knowledge, and others surfaced during the actual conduct of this research. This area of the research direction focuses on several of the key methodological issues and suggests a way to move forward.

- There are methodological issues associated with the theoretical issues discussed above regarding complex system performance and transformation. Given that the theoretical concepts can be clearly articulated, there is a need to then establish methodologies to 1) assess the level of performance of a given complex system, and 2) define an appropriate evolutionary path for that system (Keating et al, 2003b).
- Based upon development of the performance assessment methodology above and establishment of values for the dimensions of contextual element (discussed in the previous section), a methodological extension of the CSCF would be to develop an approach through which correlation analysis could be conducted considering CSCF assessment of different complex systems against the established measure of performance (or change implementation success) to determine what correlation, if any, exists between various CSCF states or

configurations and the performance (good or bad) of the complex system of interest.

- Future research should also be conducted in development of various representations or visualizations of complex system context. As discussed in Chapter II, being able to understand context is agreed to be essential in the application or execution of a wide range of systems-based approaches. Development of a representation of complex system context that is intuitive, accurate, and objective (or at least objectively based) would be a substantial contribution.

### Future Research Recommendations - Conclusions

While this list of suggested research topics or concentration areas is not by any means exhaustive or all inclusive of the research needs within the domain of systems engineering or systems analysis, it defines a number of key areas where the application of rigorous research would pay significant dividends in the world of systems-based approaches to complex systems and complex system problems.

## CHAPTER SUMMARY

This chapter presented the conclusions that were drawn from this research, specifically discussing the Meta-Element Model, inter-element relationships, and the structure of the CSCF. Implications of the grounded theory of complex system context and the Complex System Contextual Framework were then offered, focusing on both their implications to the research community as well as practitioners. Lastly, recommendations for future research directions were proposed with the emphasis in three areas: 1) increasing generalizability and transportability of the theory of complex system context; 2) using the CSCF to conduct empirical research on the elements, attributes, and dimensions of complex system context, and their influence of the system; and 3) continuing research in the area of complex system context visualization to develop tools to provide an intuitive and accurate representation of context.

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# APPENDIX A

# GUIDE FOR CONDUCT OF SEMI-STRUCTURED INTERVIEW

(This page was provided to interview participants as read-ahead)

## FRAMING THE RESEARCH

This interview is part of a doctoral research project within the domain of systems science. The research is focused on developing a framework for the construction and articulation of system context in addressing complex systems problems. The interview you are about to participate in is one element of this research, which is intended to learn how systems scientists, systems engineers, systems analysts, and other systems practitioners view system context; and to understand how they operationalize that perspective when applying systems-based analytical methods.

The following research perspective of complex system context was developed to help frame the research project. Complex system context

- includes events, incidents, factors, settings, and circumstances that in some way act on or interact with the system, perhaps as enabling or constraining factors.
- includes enacted elements of system environment and captures system / environment interactions and interdependencies.
- is a construct or interpretation of properties of a system that are necessary to provide meaning to the system, above and beyond what is objectively observable.
- is reflexive in nature, resulting in context further defining the system while the elements of the system are part of the self-same context.
- does not have a true reality. There is no "correct" interpretation of context.

## SEMI-STRUCTURED INTERVIEW GUIDE – TOPICS TO BE DISCUSSED

***General Information:***

1. Participant's academic and/or experiential background
    a) Systems theory
    b) Systems-based approaches
2. Historical / biographical information on involvement in the conduct of systems (problem, policy, etc.) analysis.

***Systems Context – Concepts and Methodology:***

1. Thoughts on research prespective
2. Complex system / complex system problem definition
    a) Problem definition process
    b) Related terms and concepts
3. Significant influences on approach or methodologies
4. Specific systems-based methodologies employed
    a) Describe methodologies most frequently employed
    b) Why
    c) Approaches to understanding system / system problem?
5. Personal philosophy of systems
    a) Philosophical paradigm with regard to systems approaches
    b) Systems concepts:
        (1) Complementarity
        (2) Worldview

6. Regarding the most complex systems analysis conducted
   a) Project description (major phases, roles)
   b) Aspects that contributed to the complexity
   c) Methodology used in that project
   d) Approach in initial formulation of the problem
   e) Approach to understanding system / system problem
   f) Role of system context in determining approach
   g) Problems with approach taken. Better approach(es) in hindsight
   h) Problem formulation process used
      (1) Strengths
      (2) Weaknesses
      (3) Positivistic / Interpretivistic view of problem or problem system
      (4) Context versus environment
      (5) Problem
         - Framing
         - Setting
         - Seizing
         - Defining
         - Discovering
         - Formulating

***Closing:***

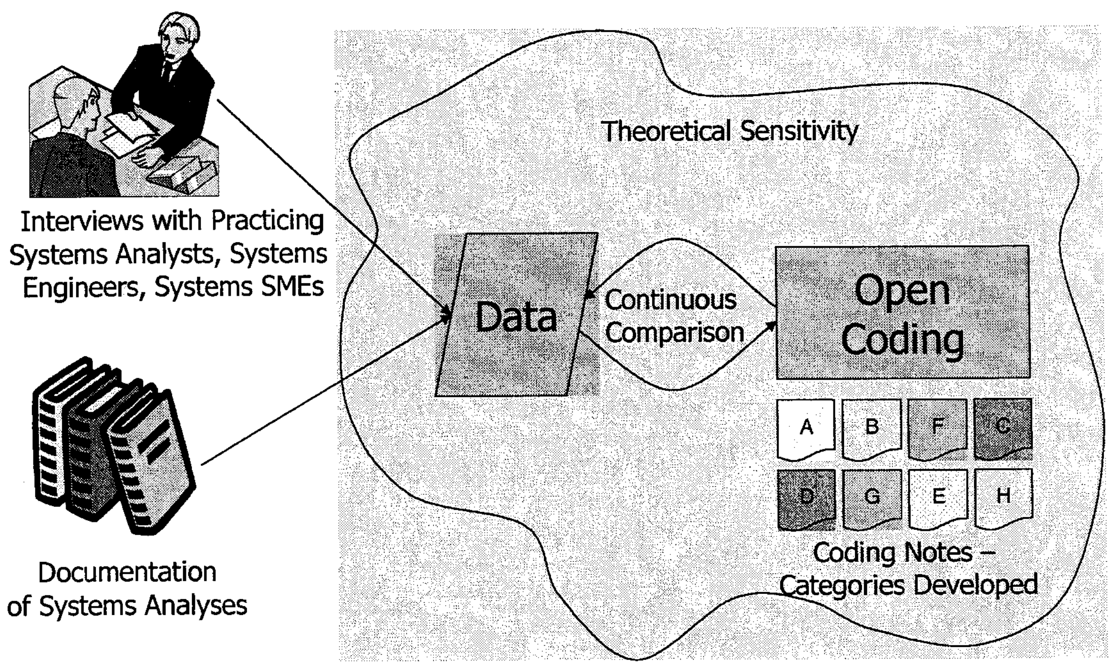
7. Advice to someone who was about to begin complex system / complex system problem analysis

8. Others who might contribute to research on system context
9. Organizational point of contact for reports about previously conducted analyses
10. New ideas or concepts stimulated by the interview
11. Additional comments from participant
12. Follow-on contact
    a) Procedure to reengage with participant as necessary
    b) Agreement to meet for "member checking" of interview notes
    c) Desire for follow-on information regarding research

# APPENDIX B

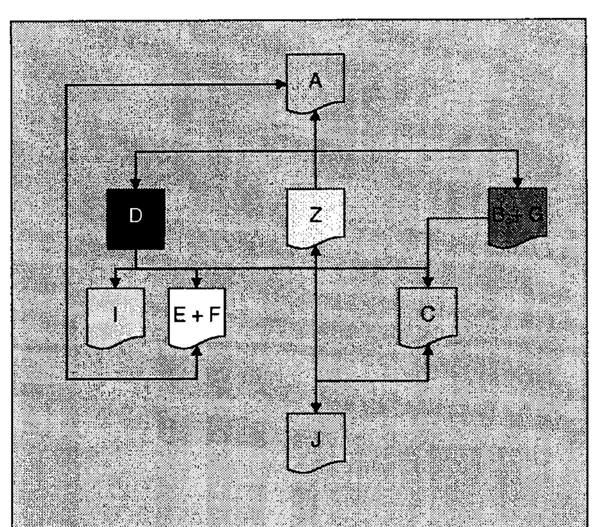
## ILLUSTRATION OF PHASES OF GROUNDED THEORY

## Open Coding



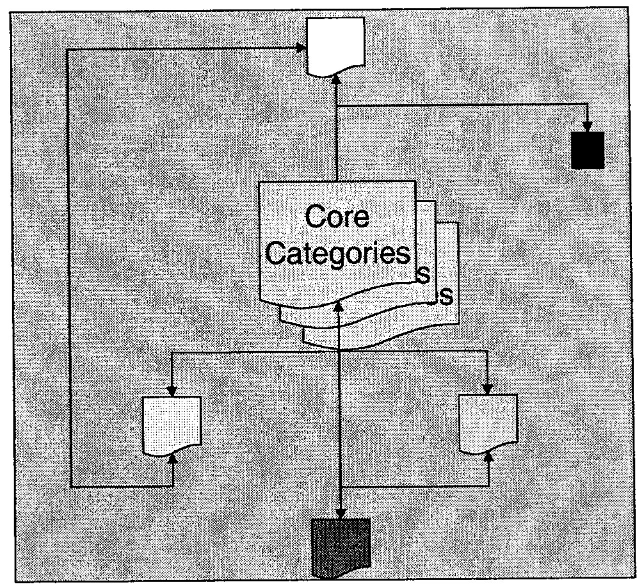

## Axial Coding

- Axial Coding Process
  - Data are reconstructed in "new" ways
  - Making new connections between categories
    - Conditions / Context / Action-interaction / Consequences



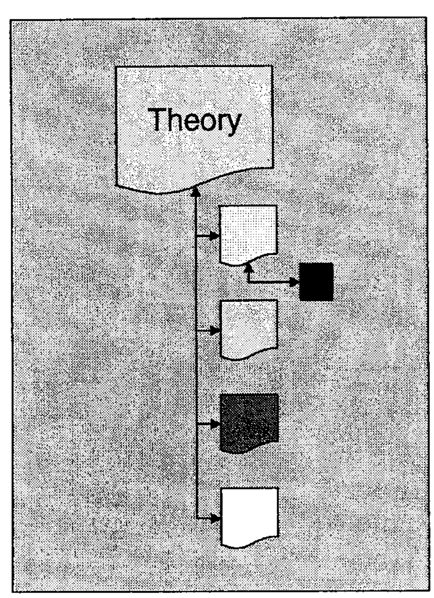
# Selective Coding

- Selective Coding Process
  - Core category or categories selected and related to all other relevant categories
    - Relationships validated
    - Categories refined / further developed where needed




# Theory Development

- Theory is developed
  - Storyline is laid out
  - Theory developed and validated against the data – completing the "grounding"



# APPENDIX C

## COMPREHENSIVE LIST OF CATEGORIES DEVELOPED DURING OPEN CODING

Analyst - Engineer
Assumptions
Boundaries
Changes in Methods
Complexity

Constraints to Analysis
Culture
Defining System Nodes
Defining the Problem
Defining the system
Environment
Experts
Hard
Hard - Soft Continuum
Internal Politics
Leaders
Learning about the System
Linkages
Methodology Issues
Models
Organizations
Parochial Perspective
People Issues
Perspectives
Perspectives or Worldviews
Preconceived Ideas
Problem Owner - Decision-Maker
Project Teams
Purpose
Quantitative vs Qualitative Approaches
Resources
Risk and Uncertainty
Roles
SE-SA-OR-OA
Soft
Stakeholders
Strategic vs Tactical
System Change
System Communication
System Engineering Customer
System Outputs / Products
System Questions
System Transformation
Systems of Systems
Systems Thinking
Temporal
The Analyst's Toolkit
Top-down vs Bottom-up Approach
Unintended Consequences
Values

# APPENDIX D

## INITIAL GROUPING OF CATEGORIES DEVELOPED DURING TRANSITION FROM OPEN TO AXIAL CODING

| Human Elements |
|---|
| Analyst - Engineer |
| Culture |
| Experts |
| Internal Politics |
| Leaders |
| Parochial Perspective |
| People Issues |
| Perspectives |
| Perspectives or Worldviews |
| Preconceived Ideas |
| Problem Owner - Decision-Maker |
| Project Teams |
| Roles |
| Stakeholders |
| Strategic vs Tactical |
| System Engineering Customer |
| Values |

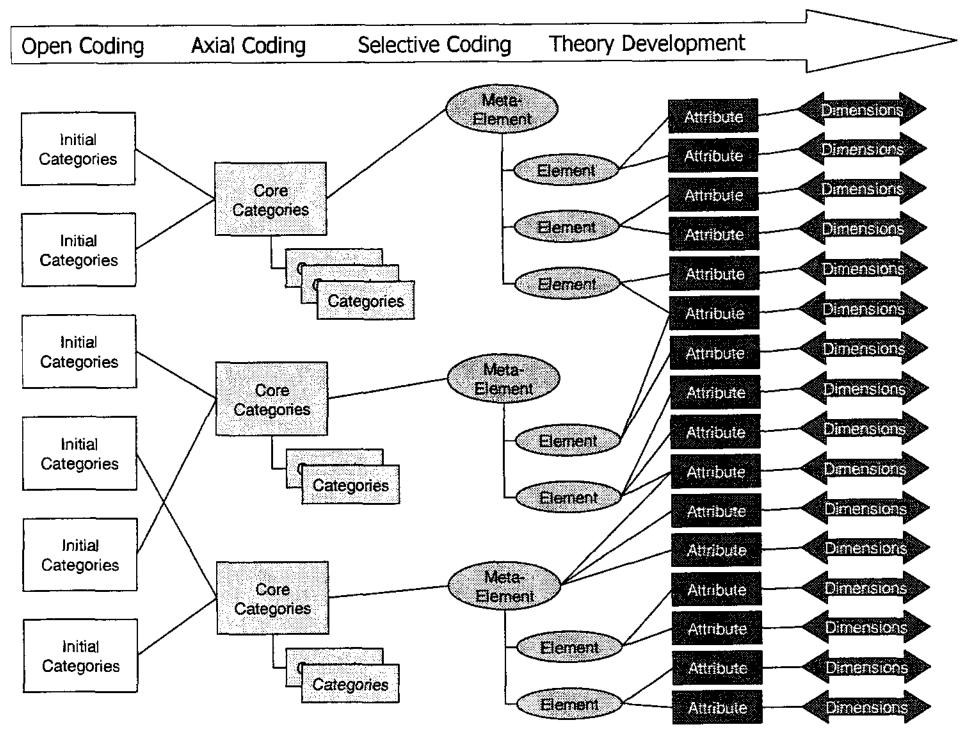
| Systemic Elements |
|---|
| Complexity |
| Constraints to Analysis |
| Defining the Problem |
| Hard |
| Hard - Soft Continuum |
| Linkages |
| Organizations |
| Purpose |
| Resources |
| Risk and Uncertainty |
| Soft |
| System Change |
| System Communication |
| System Outputs / Products |
| Systemic |
| Systems of Systems |
| Systems Thinking |
| Temporal |
| Unintended Consequences |

| Methodological elements |
|---|
| Assumptions |
| Changes in Methods |
| Defining System Nodes |
| Defining the system |
| Learning about the System |
| Methodology Issues |
| Models |
| Quantitative vs Qualitative Approaches |
| SE-SA-OR-OA |
| System Questions |
| System Transformation |
| The Analyst's Toolkit |
| Top-down vs Bottom-up Approach |

| Environmental Elements |
|---|
| Boundaries |
| Environment |

# APPENDIX E

# MAPPING OF GROUNDED THEORY CATEGORIES TO COMPLEX SYSTEM CONTEXTUAL ELEMENTS



# APPENDIX F

## PEER REVIEW PROCEDURES

According to Cresswell (1994), internal validity (the accuracy of the information and whether it matches reality) of a study can be increased by showing convergence among different investigators by having one or more researchers "provide an 'audit' trail of the key decisions made during the research process and validate that they were good decisions" (Cresswell, 1994, p. 158). That was the primary objective of the peer review in this research - to increase the internal validity or credibility of the research by having other researchers agree to the soundness of the logic applied by the researcher in analysis, coding, conceptual construction, and research decisions. There was not a requirement that the reviewers agree with the substance of the research findings, but rather that they find the approach to be intellectually and methodologically sound in order to support the internal validity of the study. These reviews incorporated in the research a means for having other researchers audit and verify the approach taken and the decisions made by the researcher. This review process proved to be invaluable to the entire research effort.

A total of four peer reviews were conducted, using students enrolled in the Old Dominion University Engineering Management and Systems Engineering PhD program as peer reviewers. The same two reviewers conducted all of the review sessions, which allowed the reviewers to build an understanding of the research over time, and minimized the amount of time required for preparation and review, especially in the latter stages of the research when the volume of information was considerable. The engineering background of the reviewers proved to be a positive aspect of the reviews in that it required the researcher to work hard to convince them of the validity of the qualitative research methodology and the grounded theory method specifically because of its not being broadly utilized in the engineering domain.

The following process was used to conduct the peer reviews:

1. Reviewers were provided an overview of the research to date. With one exception, this overview was given to both reviewers at the same time. The exception was driven by schedule conflicts, and in that case, the same information was provided to both reviewers. The overviews included:
    - Research Design / Methodology – A comprehensive overview of the research design, methodology, etc. including a review of grounded theory methods was provided at the first peer review and was reviewed as necessary in subsequent sessions.
    - Data Collection Status – The status of data collection was presented, with specific discussion on sampling decisions (e.g., selection or de-selection of participants) and data collection problems or issues.
    - Data Analysis Status – The analytical phases that had been completed and phase(s) currently in progress were discussed. Status of grounded theory coding process was presented, including coding decisions, category relationships, and emergent concepts. N6, the analytical software tool, was used to show current state of grounded theory analysis.

2. In conducting the peer review, the reviewers addressed the following:

**Data collection**

- Were participants and documentation selected in accordance with the criteria specified in the research proposal?
- Was the breadth and depth of the sampling consistent with the researcher intent?
- Was a specific methodology used in selection of data sources? What was the approach and was it applied consistently?

**Open Coding**

- How was the data analyzed?
- How did the researcher ensure he was remaining close to the data?
- Was the researcher successful in eliminating or minimizing the influence of preconceived concepts?
- Are category names assigned logically derived from the data and connected to the data?
- Does the researcher clearly tie the abstractions denoted by the names to the data and are these connections reasonable?
- When the category meanings are compared across all of the data sources is there consistency of meaning?

**Axial Coding**

- Are the inter-category relationships well-developed and understandable?
- Did the researcher clearly describe and document the basis for the relationships?

- Were category "roll-ups" well justified by the researcher?

**Selective Coding**

- Did the researcher adequately support the selection of the core category(ies)?
- Do the relationships between categories still fit, or if not, were they redefined/revalidated?
- Did the researcher tie the core category with other categories to begin development of the theoretical story line?

**Theory Development**

- Is the theory as presented fully supported by the data and analysis?
- Did the researcher adequately document the "audit" trail of the logic that supports the theory?

**Framework Development**

- Does the framework adequately fulfill the research objective of being a high-level conceptual model of complex system context?
- Is the framework fully supported by the grounded theory developed from the research?

# APPENDIX G

# PEER REVIEW OUTCOMES

**Peer Review I – April 13, 2005**

**AGENDA**

Introduction
- The Problem
- Background and Purpose of the Study
- Research Questions
- Limitations and Delimitations

Research Methodology
- Grounded Theory Method
- Rationale for Selection of Grounded Theory Method

Research Design
- Phases of Research
- Participant / Documentation Selection
- Validity and Reliability

Project Plan
- Issues, Challenges, and Barriers to Research

**OUTCOMES**

3. Concerns raised by reviewers during Research Design segment of agenda about data collection strategy and participant selection process. Reviewers' primary concerns were size of sample and lack of randomness in sampling strategy.
   - Explained purposive sampling techniques and spent quite some time talking about how purposive sampling is a rigorous and valid sampling methodology, especially in cases such as this research, where the data is from a qualitative data set, where the richness and denseness of the data is more the focal point than the sample size.
   - Another part of the sampling discussion went into some detail on the concept of maximum variation sampling, which was employed in the research. In this approach, the researcher selects a sample with variety

across one or more key characteristics. Then looks for commonality of experiences or behaviors through observation or interview.

**Conclusion:** The most significant result of this discussion was agreement between peer reviewers and researcher that, as the research progressed, the sampling process needed to be totally transparent and needed to demonstrate that sufficient care was being taken to be sure that sampling decision were made consistently and in accordance with the criteria specified in the research design.

4. Discussed grounded theory methods focusing on reviewers' concerns with the open coding process and how the influence of preconceived concepts was being minimize or controlled.
   - The open coding process was explained. Examples of individual interviews were presented and reviewers were shown how the coding was being done. Examples of several coding nodes were also presented including a 'striping' report, which showed relationships across different nodes.
   - With regard to theoretical sensitivity, reviewers were shown how the open coding categories were directly connected to the data and the category naming structure being implemented was drawing directly from or connected to the data.

**Conclusion:** For researcher, discussion reinforced importance of coding rubrics and of maintaining consistency in approach as a primary building block of validity. Provided reviewers with better understanding of the execution and implementation of the data analysis methodology.

**Peer Review II – May 20, 2005**

**AGENDA**

Review

- Purpose
- Research Questions
- Research Design

Participant Information Update

Grounded Theory Method Overview

Data Analysis Update

**OUTCOMES**

1. During participant update, reviewers had questions about specific selection decisions regarding qualifications of several interviewees.
   - Explained all decisions and how each participant met either the academic or the experiential selection criteria, and how a number of them met both.

   **Conclusion:** Increased research validity by providing reviewers in-depth explanation of sampling decisions so that they could assess them and determine if the researcher had met the level of rigor required in purposive sampling strategy. Reviewers agreed with decisions that were made. Commented that researcher may have to explain issue of lack of diversity (e.g., gender, race, etc.) of sample, but agreed that sampling was done correctly.

2. During data analysis discussion, reviewers requested amplification on the iterations that were being made between open and axial coding.
   - Discussed how the procedures were being carried out. Gave a demonstration of the N6 software and how the categories were manipulated.
   - Presented several examples of coding memos which documented categories – why they were developed, what the category consisted of,

why categories were changed, renamed, merged, split, etc. during axial coding.

**Conclusion:** Reinforced structure and process of data analysis for reviewers. Demonstration of software allowed reviewers to see how the coding was actually being done, adding significantly to their understanding of the grounded theory method and increasing their confidence in the data analysis approach.

**Peer Review III – July 7, 2005**

**AGENDA**

Research Purpose Review

Research Design Review

Peer Review III

- Approach
- Desired Outcomes

Axial Coding – Final Results

Selective Coding

Theoretical Construct

Road Ahead

- Theory Development
- Framework Construction

**OUTCOMES**

1. Presented draft of final axial coding results and had follow-on discussion of status of selective coding phase and initial thoughts of emergent theoretical constructs. During this discussion, reviewers raised questions about how the concept of system context was being characterized, and in particular the relationship between elements, attributes, and dimensions. Of particular concern was that the concept of dimensions needed further development and explanation.
   - Explained how these aspects of context had been conceptualized at the beginning of the research and what had emerged during the data analysis. After extensive discussion, all (reviewers and researcher agreed that

more work was required to flesh out the concept of dimensions and the attribute-to-dimension relationship.

**Conclusion**: More than any other peer review, review session III proved the true value of this process. Because of the critical look taken by the reviewers, an important gap was uncovered in the conceptual development and analysis. As a result, the element-attribute-dimension relationship was amplified in the dissertation to be sure that these parts of the theory of complex system context were clear.

**Peer Review IV – September 17, 2005**

**AGENDA**

Research Design Review

Taxonomy of Elements

The Meta-Element Model

Theory of Complex System Context

- Contextual Factors of Elements
- Contextual Influence
- Complex System Context

Complex System Contextual Framework (CSCF)

**OUTCOMES**

1. Presented research results including detailed descriptions of elements of complex system context, attributes and dimensions. Discussed emergent theoretical constructs including: Meta-Element model, which defines the four high-level meta-elements of context and explains the relationships between them; and series of high-level models of complex system context. Reviewers questioned how relationships discussed in the models were identified and developed.
   - Explained how the analysis process had not only developed the categories that mapped to the elements of complex system context, but also considered the relationships between categories. Presented several

examples of cross-category matrices showing the relationships between the different contextual concepts.

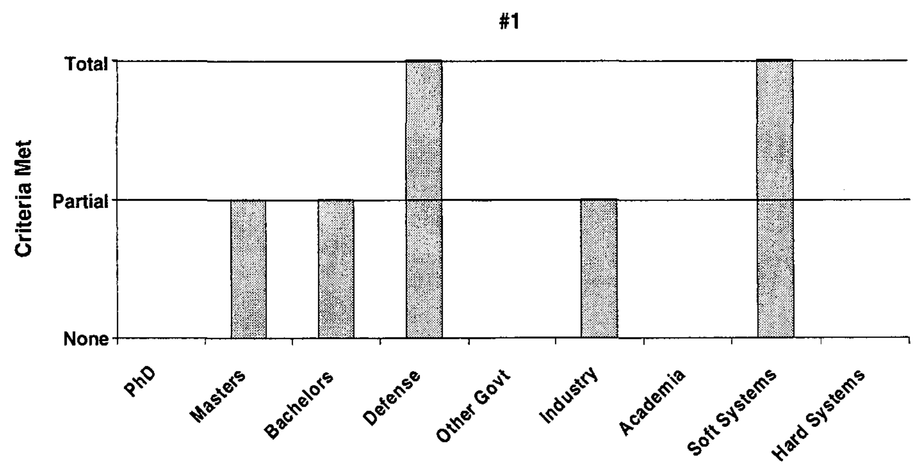
**Conclusion**: This critique of the theoretical constructs provided much needed review and feedback to the researcher. Discussing the concepts that had emerged and how the storyline came together brought to light several areas where the researcher needed to rethink or refocus the description of the theory.

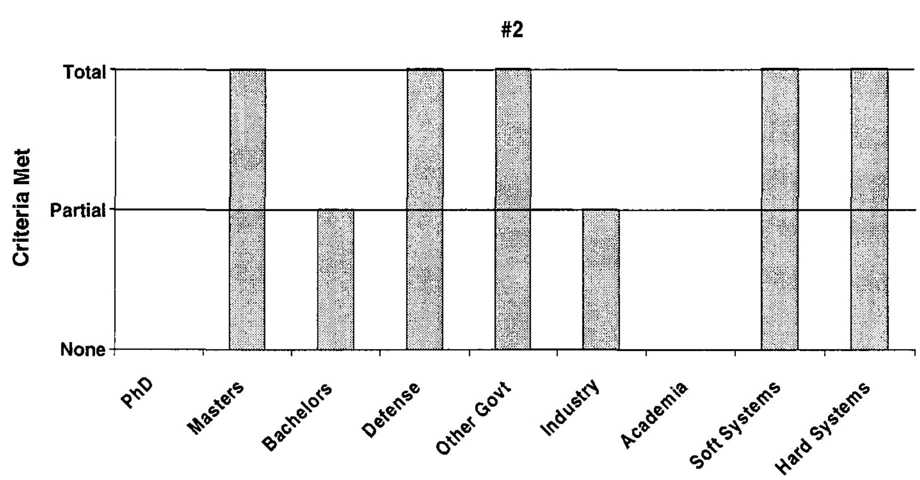
2. Explained the CSCF and discussed how it was developed, potential implications, and future research opportunities it presented.

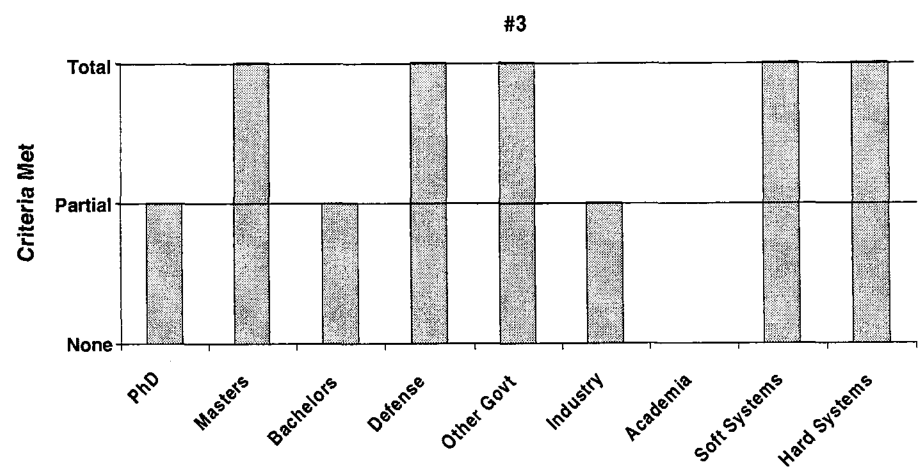
   **Conclusion**: This discussion of the CSCF was helpful in developing the conclusions and implications chapter of the dissertation.

# APPENDIX H

## SUMMARY OF INTERVIEWEE QUALIFICATIONS

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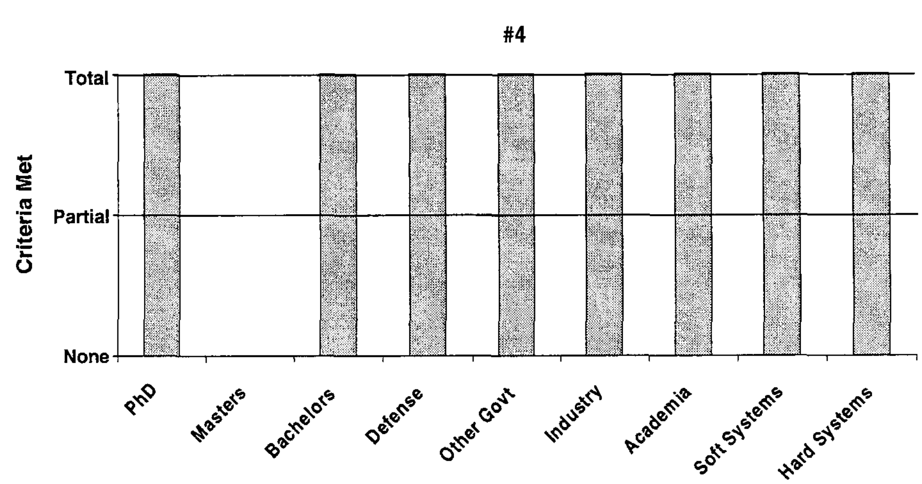
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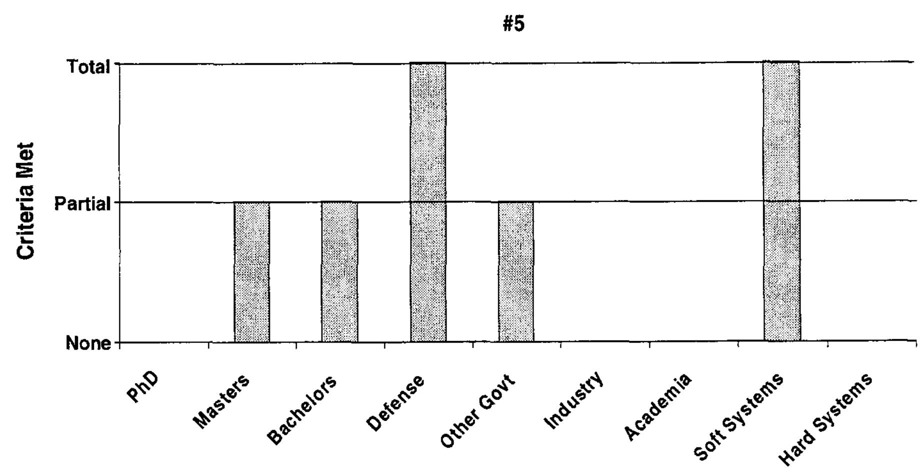
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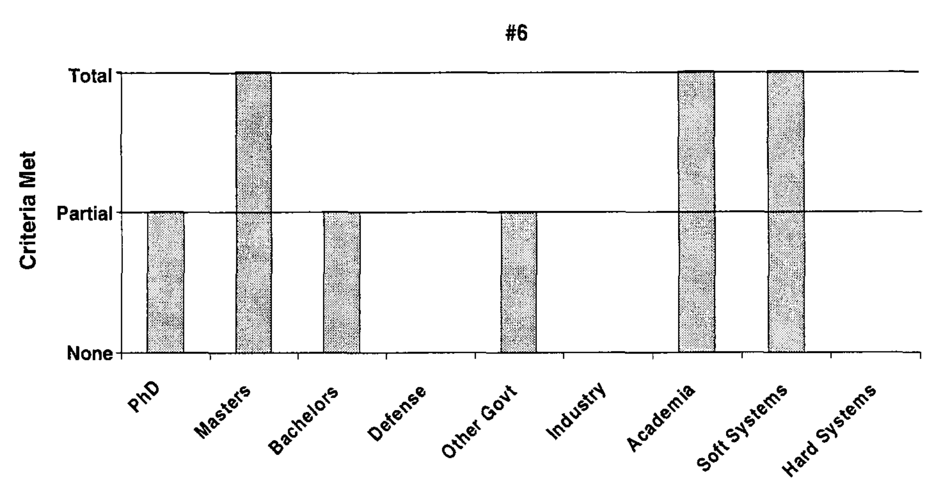
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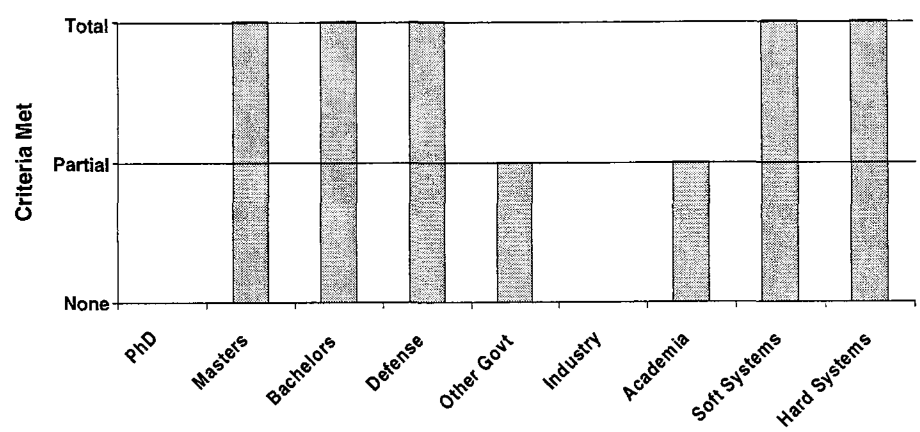
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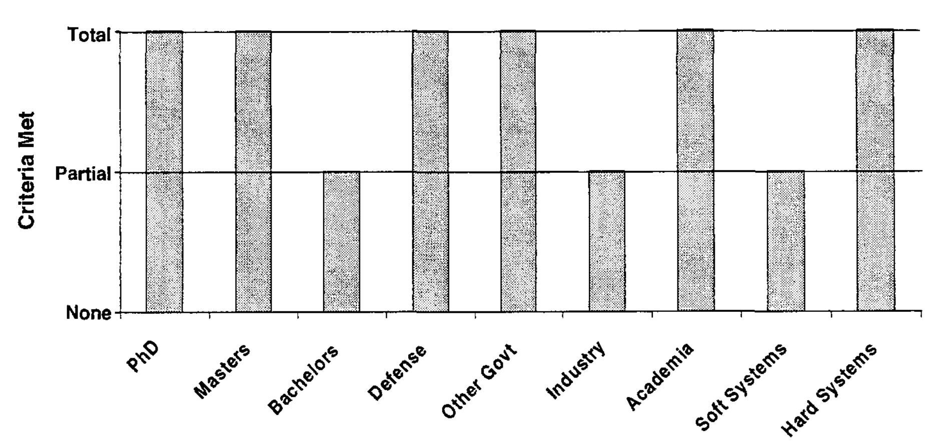
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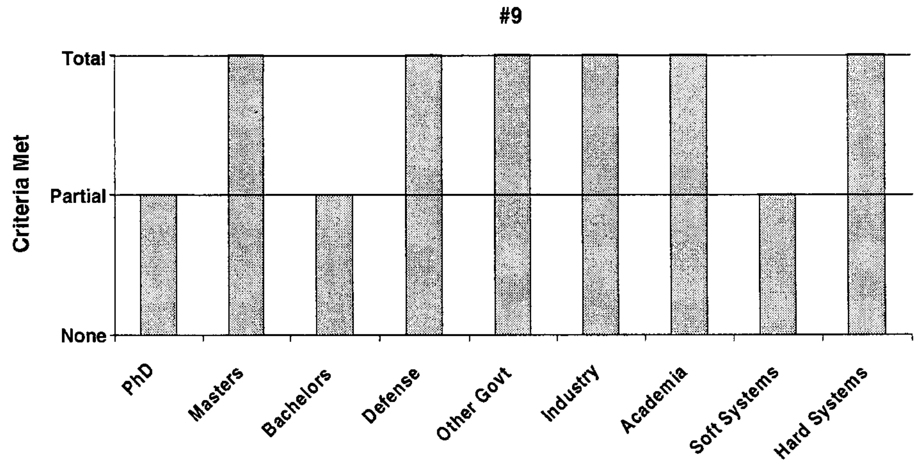
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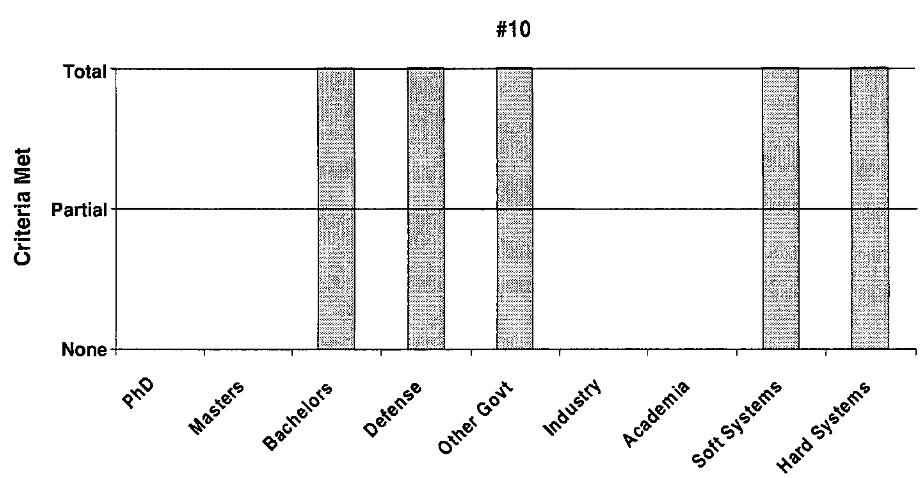
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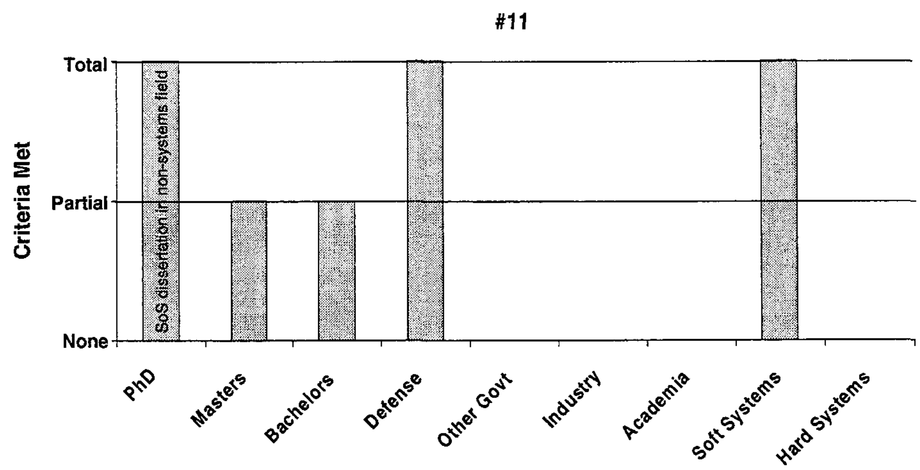
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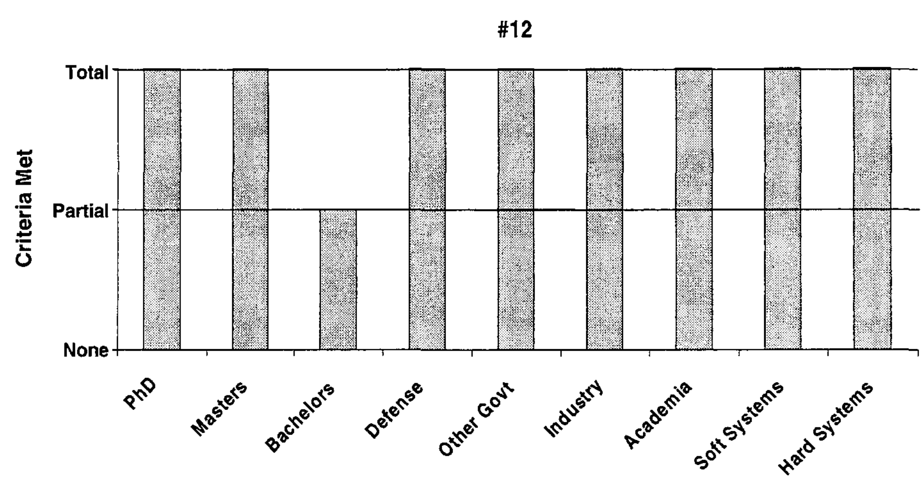
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# APPENDIX I

## DETAILED ELEMENT DESCRIPTION - PODM

*Human Meta-Element – Role-Related – Problem Owner/Decision-Maker*

The first Role-Related element to be presented is Problem Owner/Decision-Maker (PODM). This refers to an individual or group who, because of their position within the organization or system, is (are) responsible for making decisions concerning the complex system and complex system problem of interest. The analysis showed that the PODM is a critical role in any systems engineering or systems analysis initiative involving complex systems, and the manner in which the PODM interacts with the system and the engineering effort is key to being able to successfully apply a systems approach to a complex system problem. Four attributes were identified in association with this element of context: Identity/Authority; Knowledge/Experience; Problem Concept; and Relations. Below are the attributes and associated dimensions of the element Problem Owner/Decision-maker.

**Problem Owner/Decision-maker – Attributes and Dimensions**

| Attributes | Dimensions |
|---|---|
| **Identity/Authority** | Identification; Number; Process; Designation; Resource Control |
| **Knowledge/Experience** | Domain Knowledge; Systems Knowledge; Decision-making Experience |
| **Problem Concept** | Expectations; Concept Flexibility; Constraints/Limitations; Objectives |
| **Relationships** | Stakeholder Relationships; Direct Support Roles |

**Attribute – Identity/Authority**

The first attribute associated with the PODM is *Identity/Authority*, referring to the identification and make up of the PODM, and the range of authority associated with this role. This attribute addresses issues such as: Is the PODM clearly identified? Is the PODM a single individual or a group? Do all who need to know, have a clear understanding of the PODM as defined within the system of interest? Does the PODM have control over the requisite system resources to implement the decision that may be made? During the interviews, terms such as customer or client, were frequently used interchangeably with the concept of PODM. The following excerpts from the research interviews illustrate the importance of PODM *Identity/Authority* and capture the discussion regarding the associated dimensions.

**Identification/Number/Designation:**

"...[our customers were] *originally a triumvirate, but now there's four: Assistant Secretary of Defense for NII, Vice Chairman of the Joint Chiefs of Staff, Undersecretary of Defense for AT&L, and also U.S. Director of Intelligence."* (#10)

*"I'm not the decision-maker, generally the customer is."* (#10)

*"That... and also it has to do with who should be making those decisions? When you raise those decisions to an ever higher level in an organization, you add time. When you lower those decisions to a very operating level you take away time, but now, you have to inform all of those decision-makers of the sort of balance and priorities and so forth."* (#12)

*"Actually most of our tasks are like the one that you described. I have to deal with a committee of people [PODMs]... and the people we're dealing with may not be in the same office, because they have different centers. That is a problem to us. We have to address the concerns of almost everybody."* (#8)

**Process:**

[As PODM] *"I always presume that I've got ultimate responsibility and will probably always engage in assisting in the solution as well so that I'm comfortable... because I'm going to have to be the owner of the future problems that come out of that solution."* (#6)

*"You definitely need to modify the approach... depending on the individual* [PODM].... *we're not the decision-maker. The decision-maker will act whether we provide product or not."* (#10)

*"...the last thing you want to do is to do an assessment or an analysis where you either... assumed away a factor which he* [PODM] *thinks may be important to him, but then you also have the other problem which is that you don't want to over burden him where things which you've now told him he has to worry about which he may not have to worry about, because he has no influence."* (#7)

**Resource Control:**

*"They wanted something bad and we just told them upfront, "You don't have the time... you don't have the money... you don't have the resources... So you're not going to get it. However, this is what we think we can do for you." And they went, "Fine... thanks." But they still wanted the Cadillac. So we still had to go back... and we knew we were on thin ice... but we had to go back periodically... and just say HELLO... remember."* (#7)

**Attribute – Knowledge/Experience**

Another attribute that emerged as critical was the level of knowledge/experience of the PODM. This attribute considers the ability of the PODM to understand the system in which the problem lies, the approach being taken to address it, and the process of making complex decisions. Those aspects of the PODM associated with their level of knowledge within the domain of the system of interest (Domain Knowledge); level of knowledge of systems concepts, principles and approaches (Systems Knowledge), and level of experience in a decision-making role (Decision-making Experience) are crucial to the successful application a systems approach to a complex system problem. These specific dimensions were captured under the *Knowledge/Experience* attribute, as shown in the interview excerpts below.

**Domain Knowledge:**

*"It's awful hard to explain to them the complexity of the system. I can show somebody what it graphically looks like, and they go, "Wow." That's really it... then they just fog over, because it's hard to understand."* (#5)

*"...we'll go to these folks who actually run the control towers and talk to them about how the airport works... we'll go home and push our pencils, and then we'll go back and we'll expose what we are saying to those guys. And we're not done until they say 'that's it.' I was very tickled by one of the responses from a guy who said for sure he does not understand the mathematics, but by golly, what the output is, that is what our airport does."* (#9)

*"However, they do have, in some cases, strong views in the domain of their work. Simply because they are very familiar with the domain that they are work with...*

*they may sometimes extend their knowledge out of the boundaries they are working on."* (#8)

*"For PhDs, who tend to be experts in their particular field, and if you want to convince them you have to be very good in terms of modeling... to earn their respect. For the Colonels, they tend to not pay particular attention to the technical details. They want 'Give me the answer' and also they focus more on the assumptions. 'Why is it like this?' and so forth."* (#8)

**Systems Knowledge:**

*"I think it can be absolutely crucial because if your client doesn't have a good feeling, viscerally about what you're doing, then that builds in tension that is almost certain to lead to difficulties."* (#9)

*"my target audience is the military or political decision-maker. So, part of it is trying to take some of the good things out of systems theory and educate non-technical people..."* (#11)

*"The way that we resolved that* [lack of systems knowledge] *was, we spent a fair amount of time talking. He was, and still is, a very sharp guy, and so it was easy to do that. That isn't always the case. What I've found is that the better... the smarter and better educated the client, the more quickly you get across that delta."* (#9)

*"And I think the bottom-line on that example is that you don't have to educate your client to the point of following your analysis, if you can show him that what you say is going to happen, it feels good to him because that's what he thinks is going to happen, too."* (#9)

[on the need to give people a primer on systems] *Oh yeah... always... always. Depending on the client you are dealing with... some are more sophisticated that others... and some of them are repeated clients and then we have less education to do."* (#8)

**<u>Decision-making Experience</u>:**

*"You know... you get the collective wide experience of some very senior, powerful people that have a wealth of decision-making experience... and oh by the way they are influential with enough of people just like them so that they can draw upon a half dozen experts... world-class experts at a moment's notice just by... 'What do you think of this?' So it becomes a matter of, you know... let's say as a military commander, you have a decision-aid that you think is just extraordinarily illustrative and valuable, and your trying to ask somebody else what... 'Hey...' you know... 'what's your take on this?'" (#1)*

*"For the Colonels, experienced decision-makers, they tend to not pay particular attention to the technical details. They want "give me the answer" and also they focus more on the assumptions. Why is it like this and so forth." (#8)*

**Attribute – Problem Concept**

It became clear during the analysis that the way in which the PODM viewed the problem and the solution space played a pivotal role in the engineering or analysis efforts. It was important to understand how much, if any, preconception was in play and as a result how much flexibility those attempting to address the problem had. This led to the identification of the PODM attribute labeled *Problem Concept*. This attribute is defined by to what degree the PODM had established expectations for the initiative;

the amount of flexibility the PODM had in the conceptualization of the problem, the kinds of constraints or limitations imposed on or by the PODM regarding the problem and approaches for dealing with it, and whether specific objectives had been set for the initiative. The dimensions associated with Problem Concept are: Expectations; Concept Flexibility; Constraints/Limitations; and Objectives.

**Expectations:**

"[my organization] *actually has this idea of generations of policy analysis... where the first Generation was we use our OR models to go tell decision-makers – "Do option 'D'."* (#4)

*AT&L, who was the client, was asked to do this... no doubt they were the client...* [the PODM] *had a, what I would consider a traditional acquisition mindset... where he wanted... he wanted to see schedules, he wanted to see timeframes, he wanted to see programs come together, he wanted to see dates when this equipment would be interoperable with each other..."* (#4)

*"So, it's very important that you come to some understanding or at least a major understanding of what is it that one wants to do or is going to try and do. Part of it is in interacting with whoever the delivery is for or the customer is."* (#7)

*"...at the beginning, for four or five months, I've been working interactively with my client* [PODM] *to understand what... his problem is. And it's been back and forth and sometimes repeatedly.... we have to understand his position."* (#8)

*"...you need to find what they* [PODM] *are looking for and just show that to them."* (#5)

*"...we have to... not necessarily negotiate... but to have a dialog between us and the customer [PODM] to have a better understanding of what exactly he's looking for. I think that's very important."* (#8)

**Concept Flexibility:**

*"He* [PODM] *thought there was some relationship and we were offering none. So that... we were wrong for sure and he wasn't offering anything."* (#10)

*"...at the end we have the conclusions. For example, Mr. So-and-so* [PODM], *that's not your problem; or instead of that, this is a problem for you. ...I think we maintain the utmost objectivity in recommending our conclusions. ...the client* [PODM] *may say, "Well yes, I accept your recommendation although I disagree with it" and that's a different story. They may say, "Well can you look at another problem?" In that way, they may have a new position... whether or not, that's a different story, but in some cases they may try to steer us to the right... to some of the other problems they want to solve."* (#8)

*"You have to present the whole picture to the decision-maker. And in many cases, I think, as analysts, we cannot and in many cases we do not know what is the preference of the decision-maker. That is why you have to present a fuller picture to him."* (#8)

**Constraints/Limitations:**

"[By further constraining the problem definition]*...it becomes more tractable, but maybe less meaningful to you as the decision-maker. I've constructed a problem you don't care about anymore."* (#10)

*"I can't use as an excuse the fact that you* [the PODM] *over constrained the problem. If the good answer lies on the other side of a hard constraint, we're supposed to break the constraint... break the stovepipe... use it differently."* (#10)

*"What is the problem they have, what are the alternatives, what are the choices that they have? Sometimes it's unconstrained... often there are only a couple of them* [constraints] *that they're really concerned with. So what are the selection criteria... what's good and what's bad?"* (#10)

**Objectives:**

*"Deployment and execution occur at the individual level; strategy occurs at the top [PODM]. And how those are linked is the biggest challenge of most complex systems."* (#12)

**Attribute - Relationships**

The fourth attribute identified under the PODM element of context was *Relationships*. During the analysis, the concept emerged that there were key relationships that affected the PODM and/or the decision-making process. Most critical were the PODM's relationships with other system stakeholders and with individuals who provided direct support to the PODM and associated processes. While the relationships among all stakeholders are important, considering the unique role PODM, there is additional emphasis placed on how the PODM relates to others. This attribute emerged during the analysis as a theme that centered on a number of comments made about the PODM's dealings with others and also the degree to which the PODM does/can delegate decision-making functions to individuals in support roles. The dimensions associated with the attribute *Relationships* are: Stakeholder Relationships; Direct Support Roles.

**Stakeholder relationships:**

*"...And we were created to try to bridge the gap between those four (originally three, now four) organizations."*(#10)

*The other factor we are starting to discover* [in policy analysis decision-making],... *we're discovering stakeholders."* (#4)

*"He* [PODM] *has his constituents to satisfy and he has some service to do for them."* (#8)

**Direct Support Roles:**

*"...all of the advisory groups told us don't look at active acoustic sensors, 'This is passive, compare it with other passive.' We ultimately got to the big elephant who looked at us... looked at ME, and said, 'How come we didn't compare this to anything that worked?"* (#10)

*"There's one level between the commander* [PODM] *and what we do. The commander usually has objectives that he wants to achieve based on his mission... and he's done a military analysis on that. ...there is a group of people that will figure out* [for the PODM] *what are the effects that they want to achieve."*

*"What the commander wants to achieve, that argument has probably already been dealt with... so I don't have to deal with that so much. What I have to deal with is whether or not these nodes that we've picked... will achieve the effect. So we're about one level below the end-user* [PODM]*."* (#5)

*"...the client* [PODM] *has working for him a guy who is a good guy, but who is not quite as ready to make abstractions. So I'm singing this song and what I'm getting to is that you wind up with a model with more parameters, three parameters instead of the two that you had before. So, the guy who doesn't like to think abstractly very well, breaks into my marvelous presentation and he says, 'Well, nobody is ever going to tell you about their investments and producibliy and production technology.' So it was interesting that the sharp cat* [PODM] *interrupts me again... in the middle of my fumbling explanation to the cat who doesn't like abstractions, and says, 'No, don't you see' (he can say that because he's this other guy's boss) 'what's going on here is he's got a model because he doesn't know the parameters' which is exactly right. I think that's kind of an interesting exchange... here's this guy who can do it and does who in this case just tells his subordinate, 'No. Quit worrying about that because that isn't what's going on anyway.'"* (#9)

*"So there you had the interesting situation that you must make this set of lawyers feel good about what you're doing. That was a challenge. In this particular case, there was a very senior government lawyer* [PODM], *there was the government lawyer who was actually responsible for arguing the case* [Direct Support to PODM]... *The thing we both had to do was get the lawyer-types to feel really good about both of us. We did that... I think we were quite successful with the guy who was the man on point, who actually had to argue the case. And we did it by letting him see really did make sense and what the two approaches said was entirely consistent. So that's what we did there. Now the bosses... I don't think we did so hot, frankly. Their approach was well we've got to get up and make a judge believe you, and I don't think that they*

*were convinced that that would happen. As it turned out, the government won the case and the lawyer was kind enough to say that what we had done was helpful. But I think it may have been a surprise to the senior lawyer."* (#9)

# APPENDIX J

# DETAILED ELEMENT DESCRIPTION - STAKEHOLDER

*Human Meta-Element – Role-Related – Stakeholder*

Similar in concept to the PODM as an element of context is that of the stakeholder. For the purpose of this research, a stakeholder is an individual, group, entity, or organization that has some interest or involvement (ownership, resourcing, support, membership) in the complex system of interest; can be affected by the system or can influence it; or is either directly or indirectly impacted by the system. The analysis showed that the degree to which stakeholders buy-in to the approach, their perspectives regarding the complex system and complex system problem, the manner in which they communicate, and their key relationships are significant factors in complex systems. Four attributes were identified in association with this element of context: Involvement; Worldviews; Communications; and Interaction. Below are the attributes and associated dimensions of the Stakeholder element of context.

## Stakeholder Attributes and Dimensions

| Attributes | Dimensions |
|---|---|
| **Involvement** | Size; Type; Commitment |
| **Worldview** | Focus; Range; Flexibility |
| **Communication** | Inter-stakeholder; Analysts/Engineers |
| **Interaction** | Leadership; Personalities; Politics |

## Attribute - Involvement

*Involvement* is the first attribute of the contextual element called Stakeholder (Human Elements – Role Related – Stakeholder). The attribute *Involvement* characterizes the stakeholders as a group, and why and how specific stakeholders are concerned with the system of interest. The analysis indicates that it is important upfront to know the size of the stakeholder group (Size). Additional concepts that emerged as dimensions of stakeholder involvement included the importance of understanding, for individual stakeholders, the type of association the stakeholder has with the complex system (Type), and to what degree has the stakeholder 'bought-in' to or is willingly committed to their role in association with the complex system and in addressing the complex system problem (Commitment). These three dimensions (Number, Type, Commitment) were captured under the *Involvement* attribute, as shown in the interview excerpts below.

**Size:**

*"...what can probably be considered to be systems analysis, systems engineering, systems design... generally involved decently large numbers of stakeholders..."* (#4)

[regarding addition of more stakeholders] *"it does make it complex and the way that it makes it complex is that politically you are going to have a huge amount of churn until eventually you get to this point* [referring to where JBMC2 is today]. (#4)

**Type:**

*"But you looked at them* [analysis results from various stakeholders] *and you agreed with every data item and there were lots and lots... and I said, wait a minute... I agree with them all, they can't all be right. ... a cynic might say they were taking advantage; someone else might say, well they're building these things because they've*

*already done the analysis and that's what it led to. So how do you expect them to come up with anything different?"* (#10)

*"How do you come up with what their* (stakeholders') *needs are?"* (#4)

**Commitment:**

*"People were willing to buy-in to make it work..."* (#2)

*"...how do you involve stakeholders in the process?"* (#4)

*"So there are some parts of this Roadmap where the services aren't involved at all. That said, when the Roadmap was signed, in addition to giving everybody part ownership of it, it gave them encouragement to clean it up a little bit.* (#4)

**Attribute - Worldview**

In the process of analyzing the interviews, the concept of *Worldview* emerged as another attribute of the element Stakeholder. While the concept of worldview will be touched upon in the discussion of other elements, its importance in the discussion of stakeholders was central to understanding why the stakeholder role was so pivotal to the system and particularly to any initiative intended to change or improve the system. The dimensions associated with characterizing *Worldview* are Focus, Range, and Flexibility. Focus refers to whether the stakeholder worldviews are stakes-based or system-based, in other words, whether the primary motivations of the stakeholders tend to be centered on their own personal/organizational interests or on the interests of the complex system of interest. Range is an indicator of the breadth of differences in worldview among stakeholders. Flexibility has to do with whether stakeholders' worldviews are rigidly fixed or somewhat malleable to the views of others. The interview excerpts below illustrate how these dimensions (Focus, Range, Flexibility) emerged within the attribute of *Worldview*.

**Focus:**

*"So then we tried to do our own* [analysis], *at the last minute. Was it better? No. Any one of them* [analysis by various competing stakeholders] *was much more sophisticated. All I can say is I'm not pushing AMRAAM because I build AMRAAM, and I'm not pushing the supersonic low altitude target variant because that's what they built."* (#10)

*"So... we didn't get a whole lot of stakes-based worldview problems there."* (#2)

*"So, spend the energy on understanding what creates value for the stakeholders or the constituency in a situation."* (#12)

*"It's a lot harder with an existing system. It's because of the stakeholders issues.... There are several levels of expectation, I should say. There's the Congressional expectation, there's the OSD expectation, and then there's the expectation of the guys out here* [referring to JFCOM]*..."* (#7)

**Range:**

*"And to some extent, you want people with different perspectives, because when people have different perspectives, probably the better and more robust your system is going to be."* (#4)

*"...we did that with... the Marines and the Navy... and the Navy was both in the Gator Navy and the Blue-water Navy, so we've got three cultures. And then you've got the aviators versus the ground... so you've got 5 or 6 cultures."* (#12)

*"We will listen to a variety of people discuss the problem from their perspective – students, faculty, staff, outside of the school elements (registrar, business office) and we will try to determine at that point kind of almost triangulating from all of these various approaches, what the real problem is."* (#6)

**Flexibility:**

*"When you're dealing with stakeholders, one of the biggest and hardest things is to come up with what the overall theme of what you're doing."* (#4)

*"What I have found is that either you get to this point* [reaching consensus], *and you actually come to some sort of agreement on what the variable is, or basically the project explodes."* (#4)

*"I think it's also how well people get along inherently. I mean, I've gotten along with people with radically different perspectives on things.... But if they have a good time, and go out for a beer afterwards, then they'll probably get here* [consensus]*."* (#4)

*"Right... and the kind of people who tend to get along well are people who come in... it's sort of a balance thing. You don't want someone who's just going to sit there and not say anything...* [nor do you want someone] *who will firmly prefer their own ideas. If a person is too spongy... too kind of amorphous... you're going to churn... indefinitely. If someone comes in saying, 'we're going to do things my way... period,' the project will probably fail, especially if it is required to involve stakeholders."* (#4)

*"...in this virtual environment or this around the table environment, you need to have this meeting of the minds."* (#1)

*"And you sit down and to come out of that with all understanding the behaviors that drive success."* (#12)

*"...the key is to get everybody to agree to the assumptions going into the assessment process, because not too many people are going to argue about the assessment process itself, it's the assumptions. If you agree on the assumptions, then you're going to see where you rack and stack, and you can come up with your one-to-n list... draw a line and say, 'You make it... you're above the line. You don't.' And they can't argue too much about that."* (#7)

**Attribute - Communications**

Early in the analysis, it became clear that stakeholder *Communications* was emerging as a key attribute of the *Stakeholder* element. In order to function properly within the complex system or complex system problem initiative, stakeholders must develop effective communication channels among themselves (Inter-stakeholder) and with those involved in application of the systems approach (Analysts/Engineers). All of these connections are important to the stakeholder's ability to function within the system and be effective. Without the proper communication channels, stakeholders would not be able to understand the system, because no one stakeholder has full visibility on what the system is, what it is doing, and what problems it is experiencing. As shown in the following excerpts, Communications is an integral attribute in being able to under stand the contextual element *Stakeholder*.

**Inter-stakeholder:**

*"...you're never quite the expert on the system. You're an expert in knowing where the expert... expertise lies. You're the... I guess the 'local expert,' so to speak.... you know where the... experts are. You've either read, talked, communicated with... you know, all the above. You go to places that... sources of information that you go to... and you put that all together."* (#5)

*"Another thing that I think was very valuable and very important is that before as part of this it was... Well, it's our document and we're not going to send it through the JS136 process, and Joint Staff... you know, go pound sand. We are not doing that. That's why this version is going through the Joint Staff 136 process... a real, no kidding Joint Staff 136 process."* (#4)

*"The first reaction we get from people is who knew? How was I supposed to know that's what you wanted me to do? You never told me that. This is the one thing you've never communicated to me was what you wanted me to do. You told me what my mission was or what my job was..."* (#12)

*"Part of my job is to try to listen to all the views and interpret them and make sure everybody else hears what the other... person thinks."* (#6)

**Analyst/Engineer:**

*"Not necessarily, I think we take different approaches. For PhDs, who tend to be experts in their particular field, and if you want to convince them you have to be very good in terms of modeling... to earn their respect. You can not have a model... lousy job and so forth. For the* [non-SMEs], *they tend to not pay particular attention to the technical details. They want "give me the answer" and also they focus more on the*

*assumptions. Why is it like this and so forth. And in many cases, the PhDs may not ask the best questions. Seriously, they tend to pay attention to the details, depending on the person you are dealing with. For the other guys, they will say, "well, have you considered this?" I say yes and they take the face value of it. That's a possibility. Without understanding did I really truly take consideration of this."*

*"...as you said we have to spell out explicitly and clearly here's the premise that we take and modeling approach and result. Fine. In many cases, they'll accept it. Sometimes they* [stakeholders] *disagree. The disagreement is not they disagree with the modeling... they disagree on the premise. Ok, they say 'I don't think the economic growth will be that high or something like that.'"* (#8)

**Attribute - Interaction**

The last attribute of the element *Stakeholder* to be presented is the attribute *Interaction*. This attribute deals with the dynamics and relationships between and among stakeholders. The dimensions that emerged to describe Interaction all have to do with the interpersonal engagement of the stakeholders themselves. Interaction includes the concept of how certain stakeholders take the lead - e.g., to ensure the system engineering/analysis initiatives continue to move forward (Leadership). It also involves the personalities of stakeholders, individually and collectively, and how well they can or cannot work together (Personality). Finally, Interaction looks at the dynamics of inter-stakeholder influence and power (Politics).

**Leadership:**

*"…it seems like there's one particular person or a few people who push the way to this and maybe propose an initial diagram of what it looks like. People threw out something that was kind of normal, enough in the ballpark to get the ball rolling. There seems to be one particular person or a group of people who start the process of pushing for it."* (#4)

*"You then have a small group session in which maybe 5… 4 or 5 people* [stakeholders]… *a small group that comes together and does a lot of it* [the high-level system concept definition work]. *"* (#4)

[Is there a dynamic leader that can bring people together and is that something that helps?] *"I think it does."* (#4)

**Personality:**

*"Unfortunately, but I mean in each case it is personality driven."* (#4)

*"The political environment is always evolving. In general things seem to be politically better than what they were. Don't have the same, you know, total bashing of a lot of things that are going on. Some of this has to do with some personality changes." (#4)*

**Politics:**

*"The political environment is always evolving. In general things seem to be politically better than what they were. Don't have the same, you know, total bashing of a lot of things that are going on." (#4)*

# APPENDIX K

# EXAMPLE CATEGORY RELATIONSHIP MATRICES

The tables presented in this appendix are examples of the cross-category matrices that can be produced by the N6 tool. These examples show the number of text units that are common between the two specific elements that constitute any given intersection of the matrix. One of the main themes that emerged from analysis of these matrices is the significance of interrelationships across various elements of complex system context. Some the values in the matrices can be explained logically given the other aspects of complex system context that emerged from the detailed analysis of each individual element - for example, the large intersection between the Role-Related element *Problem Owner – Decision-Maker* (PODM) and the Perceptual element *Perspectives*. One of the attributes of the element PODM is Problem Concept, which has to do with the way the PODM perceived the problem or system. Detailed analysis of these relationships was outside the scope of this research; however, this should be part of any of the follow-on efforts toward beginning the empirical examination of the theory of complex system context.

| Human Role-Related Elements Versus Human Perceptual Elements | | Perceptual | |
|---|---|---|---|
| | | Perspectives | Culture |
| Human Role-Related Elements | Problem Owner - Decision-Maker | 150 | 1 |
| | Stakeholders | 69 | 33 |
| | Analyst – Engineer | 15 | 18 |
| | Project Teams | 14 | 6 |

| Human Role-Related Elements Versus Systemic Elements | | Systemic Elements | | | | | |
|---|---|---|---|---|---|---|---|
| | | System Purpose | Temporal | Complexity | System Transformation | System Problem | Systems of Systems |
| Human Role-Related Elements | Problem Owner - Decision-Maker | 14 | 27 | 46 | 7 | 124 | 9 |
| | Stakeholders | 18 | 32 | 14 | 3 | 96 | 1 |
| | Analyst – Engineer | 9 | 14 | 81 | 15 | 98 | 40 |
| | Project Teams | 0 | 4 | 27 | 0 | 18 | 7 |

| Human Role-Related Elements Versus Methodological Elements | | Methodological | | |
|---|---|---|---|---|
| | | Top-down vs Bottom-up Approach | System Discovery | Quantitative vs Qualitative Approaches |
| Human Role-Related Elements | Problem Owner - Decision-Maker | 18 | 55 | 17 |
| | Stakeholders | 5 | 41 | 11 |
| | Analyst – Engineer | 12 | 95 | 114 |
| | Project Teams | 29 | 8 | 14 |

| Human Role-Related Elements Versus Environmental Elements | | Environmental | | |
|---|---|---|---|---|
| | | Defining Environment | External Relationships | Environmental Change |
| Human Role-Related Elements | Problem Owner - Decision-Maker | 3 | 10 | 0 |
| | Stakeholders | 0 | 8 | 0 |
| | Analyst - Engineer | 0 | 9 | 0 |
| | Project Teams | 0 | 0 | 0 |

# APPENDIX L

# COMPLEX SYSTEM CONTEXTUAL FRAMEWORK (CSCF)

## CSCF – Human Role-Related Elements

| Element | Attribute | Dimension | Assessment |
|---|---|---|---|
| Problem Owner / Decision-maker | Identity/Authority | Identification | |
| | | Number | |
| | | Process | |
| | | Designation | |
| | | Resource Control | |
| | Knowledge / Experience | Domain Knowledge | |
| | | Systems Knowledge | |
| | | Decision-making Experience | |
| | Problem Concept | Expectations | |
| | | Concept Flexibility | |
| | | Constraints/Limitations | |
| | | Objectives | |
| | Relationships | Stakeholder Relationships | |
| | | Direct Support Roles | |
| Stakeholder | Involvement | Size | |
| | | Type | |
| | | Commitment | |
| | Worldview | Focus | |
| | | Range | |
| | | Flexibility | |
| | Communication | Inter-stakeholder | |
| | | Analysts/Engineers | |
| | Interaction | Leadership | |
| | | Personalities | |
| | | Politics | |
| Analyst/Engineer | Knowledge/Experience | Domain Knowledge | |
| | | Systems Knowledge | |
| | | Access to Experts | |
| | Systems Framework | Philosophy | |
| | | Methodologies | |
| | | Tools | |
| | Problem Concept | Expectations | |
| | | Concept Flexibility | |
| | | Constraints/Limitations | |
| | | Objectives | |
| | Relationships | PODM | |
| | | Stakeholders | |
| | | Confidence | |
| | | Authority | |

## CSCF – Human Role-Related Elements (Continued)

| Element | Attribute | Dimension | Assessment |
|---|---|---|---|
| Project Team | PT Leadership | Designation | |
| | | Leadership Approach | |
| | PT Functions | Integration | |
| | | Arbitration | |
| | | Conceptualization | |
| | | Collaboration | |
| | PT Capabilities | Team Skills | |
| | | Tools | |
| | | Lexicon | |
| | | Perspectives | |
| | | Consensus | |

## CSCF – Human Perceptual Elements

| Element | Attribute | Dimension | Assessment |
|---|---|---|---|
| Perspective | Variation | Cross-View | |
| | | Cross-Level | |
| | | Disparity | |
| | Alignment | Acknowledgement | |
| | | Discernment | |
| | | Normalization | |
| | Temporal Focus | Focal Point | |
| | | Range | |
| | Parochialism | Type | |
| | | System/Subsystem-Level | |
| | | Domain-Based | |
| Culture | Focus | External | |
| | | Internal | |
| | | Personal | |
| | | Allegiances | |
| | Formation | Extant | |
| | | Artificial | |
| | Diversity | Extent | |
| | | Identity | |
| | | Strength | |
| | Behavior | Dominance | |
| | | Desired | |
| | Values | Recognition | |
| | | Acceptance | |
| | | Differentiation | |

**CSCF – Systemic Elements**

| Element | Attribute | Dimension | Assessment |
|---|---|---|---|
| System Purpose | Intent | Commonness | |
| | | Conflict Level | |
| | Guidance | Centralization | |
| | | Alignment | |
| | | Subsystem Autonomy | |
| | | System Communication | |
| | Outcomes | Desirability | |
| | | Alternatives | |
| | Subsystem Purposes | Disparity | |
| | | Meta-system Support | |
| | | Compliance/Commitment | |
| Temporal Aspects | Constraints | Flexibility | |
| | | Decision Points | |
| | Timescale | Range | |
| | | Span/Duration | |
| | Focus | Period | |
| | | State | |
| Complexity | Type | Level | |
| | | Sources | |
| | Response | Optimality | |
| | | Adequacy | |
| | Effect | Views | |
| | | Uncertainty | |
| | | Risk | |
| System Transformation | Outcomes | Desired | |
| | | Unintended | |
| | | Adverse | |
| | Relationship Effects | Intra-system | |
| | | Inter-system | |
| | | Inter-subsystem | |
| | State | Current | |
| | | Desired/Future | |
| | | As-designed | |
| | | Actual | |
| System Problem | Definition | Constraints | |
| | | Metrics | |
| | | Consensus | |
| | | Boundary Type | |
| | | Scope | |
| | Structure | Constructed | |
| | | Objective | |
| | Linkages | Coupling | |
| | | Quantity | |

## CSCF – Systemic Elements (Continued)

| Element | Attribute | Dimension | Assessment |
|---|---|---|---|
| System of Systems | Entities | Identifiability | |
| | | Differentiability | |
| | | Hierarchy | |
| | System Linkages | System | |
| | | Meta-system | |
| | Subsystems | Quantity | |
| | | Complexity | |
| | Metasystem Purpose | Discernability | |
| | | Subsystem Alignment | |

## CSCF – Methodological Elements

| Element | Attribute | Dimension | Assessment |
|---|---|---|---|
| Top-Down/Bottoms-Up | Differentiation | Level | |
| | | Granulatity | |
| | | Uni-/Bi-directional | |
| | Frameworks | Integration/Autonomy | |
| | | Holism/Reductionism | |
| System Discovery | Current State | Problem | |
| | | Constraints | |
| | | Modeling | |
| | Alternatives | Desired Future | |
| | | Unintended Consequences | |
| Quantitative / Qualitative | Approaches | Specific-type | |
| | | Modeling | |
| | | Representation | |
| | | Selection | |
| | Assessment | Uncertainty | |
| | | Probability | |
| | | Reliability | |

**CSCF – Environmental Elements**

| Element | Attribute | Dimension | Assessment |
|---|---|---|---|
| Defining Environment | Boundary Definition | Selection Criteria | |
| | | Stakeholder Boundary Perspective | |
| | Boundary Properties | Permeability | |
| | | Elasticity | |
| | | Permanence | |
| External Relationships | Type | Direction | |
| | | Objects | |
| | | Coupling | |
| | Level | System | |
| | | Subsystem | |
| | | Entity | |
| | | Cross-level | |
| | Time | Period | |
| | | Range | |
| Environmental Change | Time | Rate | |
| | | Period | |
| | Transparency | Cause/Effect | |
| | | Predictability | |

# APPENDIX M

# PRACTICAL APPLICATION OF THE COMPLEX SYSTEM CONTEXTUAL FRAMEWORK (CSCF)

There are number of the significant implications and contributions of the Complex System Contextual Framework (CSCF) within the systems body of knowledge and in support of theoretical and methodological development in these areas. However, the CSCF also presents a significant source of function and structure that is readily applicable to those who are currently working as practitioners in the systems domain. Systems engineers, systems analysts, managers, and others struggling to deal with complex systems and complex system problems can use the CSCF to help them in their problem / system formulation efforts.

In their work to develop a System of Systems Engineering (SoSE) methodology, Keating and Sousa-Poza (2003) developed a three phase SoSE cycle, the first phase of which is the 'Metasystem Analysis' phase. This phase is focused on developing an understanding of the metasystem of interest, upon which the rest of the entire SoSE cycle will depend. It is understandable that they consider this phase of the cycle the most critical. One of the principle results of this phase is the discovery and articulation of the unique, metasystem-specific context influencing (enabling or constraining) the metasystem under study. This step of context identification is a critical aspect of any engineering or analysis effort looking at complex systems; however, the tools to perform this crucial function are just not available. The CSCF provides systems practitioners with something to serve as a starting point or point of departure for doing this contextual analysis and coming up with a description of system-specific context.

Given a complex system problem that must be addressed, one of the first things a systems professional is going to do is work to understand the problem and the associated complex system. With the CSCF in hand, there is a structure available around which a process for contextual analysis could be developed. For example, the project lead could have members of the analysis team use the CSCF as an outline for interviewing the known key stakeholders. While objective values have not been developed for the dimensions of complex system contextual elements, the interviewees could be asked to provide a subjective assessment of each of the given element-attribute-dimension combinations. Additionally, the team lead or other members of the team could do their own independent assessment based on observations or other data available about the system or problem. Once all of this data is collected, the team could merge the observations together into a single, comprehensive depiction of the context of the complex system of interest. While not to the level of being an objective or quantifiable instrument or metric, based upon the relationships developed in the CSCF, it provides organization to the data and the data collection process that is currently not available. It is further submitted, that were this approach applied over a period of time, across a range of complex systems and problems, the resultant data collected would be instrumental in moving the CSCF forward toward development of the validated, calibrated tools practitioners want and need.

Another practical application of the CSCF is in the area of development of a means by which complex system context can be represented. As in all application disciplines, once work is done by an engineer or analyst to understand some object or some phenomenon, the next challenge is how to portray their observation in a way that allows the concepts to be communicated to a broad range of recipients in a clear, unambiguous, and intuitive manner. The need to be able to develop such a representation is just as critical, if not more so, for the concept of complex system context as it is for any phenomenon in any other domain or discipline.

The CSCF puts a level of structure to the concept of context that previously was nebulous and amorphous, and provides a much needed foundation for the development of such a representation. Using the framework as the underlying schema, a large number of possible models could be developed that would depict this hierarchical arrangement of data. This representation must be consistent and easy-to-understand in order for practitioners to be able to turn their observations into an intuitive representation of system context for problem owner/decision-maker(s) and other key stakeholders. Whether graphical or in some other format, computer-generated or manually produced, developing a representation of context is an important part of furthering the application of systems-base approaches to complex problems.

These are just two examples of ways in which the CSCF can benefit systems professionals, managers, or anyone struggling to resolve or address the entire gamut of complex issues facing them on a daily basis. The CSCF delivers an invaluable tool to a wide range of hands-on practitioners who are working to bring the power of systems-based approaches to bear in the resolution of consequential and substantive real-world problems.

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