Context in Complex Systems Governance

Meggan Schoenberg

Abstract A complex system's identity and viability are directly related and affected by its context. It is important to identify, monitor, and manage (or mitigate risk) of system contextual elements. This chapter defines complex system context with respect to Complex System Governance (CSG) and provides a methodology to define relevant contextual elements for the practitioner to use for risk mitigation and governance. Leveraging the systems of systems engineering (SoSE) methodology as described in Keating and Adams, *Overview of the systems of systems engineering methodology* [2], and Crownover's complex system contextual framework (CSCF) [6] this article will help the practitioner identify and evaluate relative importance of contextual elements to maintain the viability and identity of a complex system.

Keywords Complex system governance (CSG) · Context · Contextual framework · SoSE or system of systems engineering · Complex system contextual framework (CSCF) · Contextual framework · Context matrix

1 Introduction

What is context? Context informs understanding and perspective and clarifies meaning. Understanding a painter's environment, how they perceived their environment, and life at the time of painting a specific masterpiece can add meaning and explanations for the painter's choices to use light colors or dark colors, happy faces or melancholy faces, stills or abstracts, and even the subject of the painting. In this way, context is often thought of in hindsight and upon reflection of a great masterpiece and therefore considered informative and benign. However, it can also have an effect. Consider the case of "New Coke." Coca-Cola felt pressure by its rival Pepsi-Cola who was winning the well-publicized "Pepsi Challenge" where Pepsi was chosen in a blind taste test more often than Coca-Cola. In response, they developed a new formula, tested it in their own blind taste test 190,000 times, and on April 23, 1985,

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the company chairman and CEO, Roberto Goizueta, announced at a press release the "New Coke." Much to the surprise of Coca-Cola, shares on the New York Stock Exchange dropped, and by June, the company was fielding 5,000 angry phone calls a day. Groups organized to protest and one Seattle consumer even filed suit against the company to force it to provide the old drink.[1]

> The problem, though, is that the company had underestimated loyal drinkers' emotional attachments to the brand. Never did its market research testers ask subjects how they would feel if the new formula replaced the old one. (Klein 2020)

Seventy-nine days later, "Coca-Cola Classic" was back with a corporate apology. Thankfully, they were able to recover from this oversight, but many companies and projects do not recover from their failure to recognize the context of their decisions. That is why it is important to not only look back and understand through context, but to look forward and identify context that may impact a system and the governance of that system. This chapter defines context for Complex System Governance and provides a methodology to identify contextual elements for the practitioner to mitigate costly mistakes and steer complex systems toward identified goals.

2 Defining Context in Complex System Governance

A Context Vignette—How context matters to system viability and identity
The manager of a database development team in a software development company had worked hard to improve moral, productivity, and quality of the team after accepting the position. The projects they worked on were deployed and actively used 24 hours a day, 7 days a week. The team rotated being on call after hours to fix bugs in the live environment that hindered sales. Prior to her efforts the person on call normally spent most nights of their weeklong, after-hours duty, fixing bugs. Some nights over a million dollars in revenue was lost due to software bugs. Within 6 months after implementation of measures to improve moral, productivity, and quality, no bugs were identified as a result of their work in production and the whole team slept well at night. For a brief period, the team's moral was high. After a few months of continued rest, the new manager started sensing moral declining again. Not understanding how this could happen when the team was getting rest, quality of the code was at its highest ever, and the team produced more code than any other division of the company; she began to look at the environment for clues. She quickly discovered that at the monthly awards and recognition meetings the other divisions were getting all the awards and her team was only briefly recognized when they came to the rescue of the other teams. The company had a system to reward heroic efforts in the middle of the night, but no system for rewarding good quality. The perception was that the other teams were working harder and deserved more credit. The new manager attempted to explain this oversight to her boss and part-owner in the company who could not understand as he had no real experience with software development. He decided to combine the successful database development team with another team who received regular heroic awards. The new manager left the company. Within 18 months, the company was out of business.

[1] Event and data regarding the Coca-Cola case were extracted from www.History.com (Klein 2020).

The term context is not easily defined and even harder to articulate where it starts and where it ends. “Context shifts and dances, it slips and sides. It insists on its mystery, yet it demands we come to terms with it every single day” [7]. The word “context” is like the word “love”; we tacitly understand it and try to define it with other words, but always seem to fail in capturing its full meaning. To understand what the word means, we have to ironically understand the context for which it is used. In this chapter, we discuss context with respect to complex systems and Complex System Governance (CSG).

Systems theory offers the contextual axiom: *Meaning in systems is derived from the circumstances and factors that surround them* (Keating and Bradley, Complex System Governance Reference Model, 2015). For this reason, CSG metasystem five star (M5*), system context, is a function intrinsically linked to policy and identity, metasystem five (M5). The M5 function provides direction, oversight, accountability, and evolution of the system. The M5 focus includes policy, mission, vision, strategic direction, performance, and accountability of the system such that (1) the system maintains viability, (2) identity is preserved, and (3) the system is effectively projected both internally and externally. Figure 1 is provided as a reference point for CSG metasystem functions [9]. It is no wonder that being able to articulate the circumstances and factors surrounding a complex system is an important factor to describe the system’s identity. However, it is a little harder to understand the importance and relevance of context and being able to articulate system context in order to maintain viability and preserve identity of a system. The first context vignette shows how a new manager’s failure to understand the context of her development team with respect to the company culture and experience level of the leadership caused the identity and viability of the team and her position to be redefined. When the leadership of the company failed to understand the contextual environment, the company was lost. This example is given to show the importance of understanding context and how it can have severe and possibly fatal results on the viability of a system when not understood, monitored, and governed.

Specifically, ***metasystem five star (M5*)—system context*** is focused on the specific context within which the metasystem is embedded where context is the set of circumstances, factors, conditions, or patterns that enable or constrain execution of the system.

Before going any further, it is important to discuss the definition of context within CSG. While it appears intuitive to say context is the set of circumstances, factors, conditions, or patterns that enable or constrain execution of the system, it is not intuitive when you attempt to differentiate what is considered context and what is not. This is true because contextual elements are part of the system, part of the environment, and part of the interactions.

Within CSG literature, context is consistently defined as “the set of circumstances, factors, conditions, patterns, or trends that enable or constrain execution of the system” [9]. CSG considers the environment as separate but related. Environment is defined as “the aggregate of all surroundings and conditions within which a system operates” [8]. If you are confused, do not worry, there is good cause to

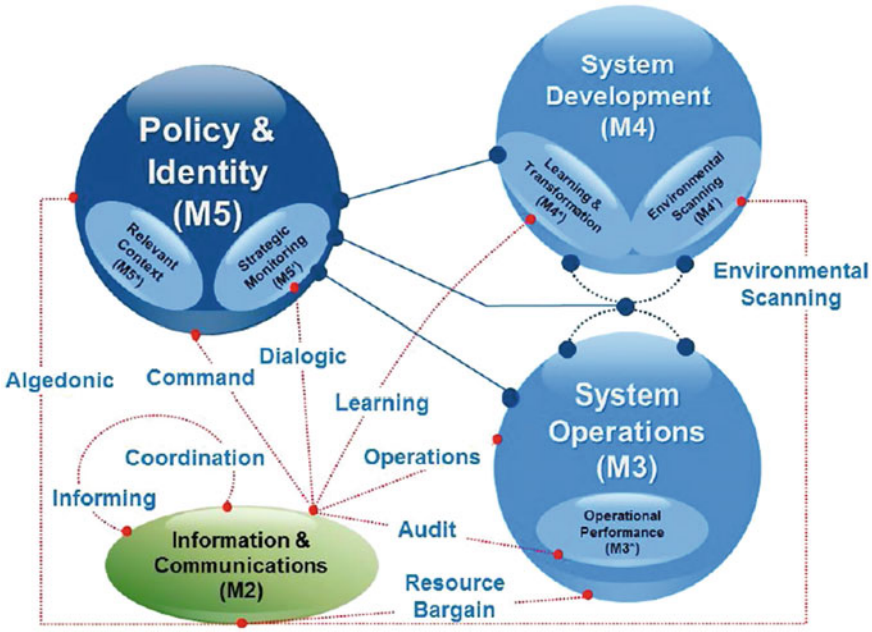

Fig. 1 Main CSG functions

be confused. In the book *Digital Ground: Architecture, Pervasive Computing, and Environmental Knowing*, Malcolm McCullough says:

> "Context" is not the setting itself, but the engagement with it, as well as the bias that setting gives to the interactions that occur within it. "Environment" is the sum of all present contexts. [10]

In Crownover's dissertation, however, the environment is explained as everything outside the boundary of the system that "touches" the system but does not necessarily act on the system. Where context includes elements within, on, and around the system that have an intimate relationship with the system rather than a mere coexistence [6]. These definitions appear to be nearly opposite. However, if McCullough is implying that an environment is the sum of perceptions of all that have interacted with a setting, then he is really not that far from the CSG complimentary axiom and principle that a complex system is described through the varying world views of those that perceive it and by reasonable correlation, so is our understanding of the context of a complex system. For clarity of purpose, this book will differentiate a complex system context from its environment as Crownover describes, acknowledging that perception is always in the eye of the beholder. Figure 2 shows a complex system embedded in its environment and context. The complex system is not cleanly defined, and similarly the context is not cleanly defined. The environment is external to the system and only becomes a part of the system context when it is engaged. A definition of a specific complex system environmental element is based on the world views of

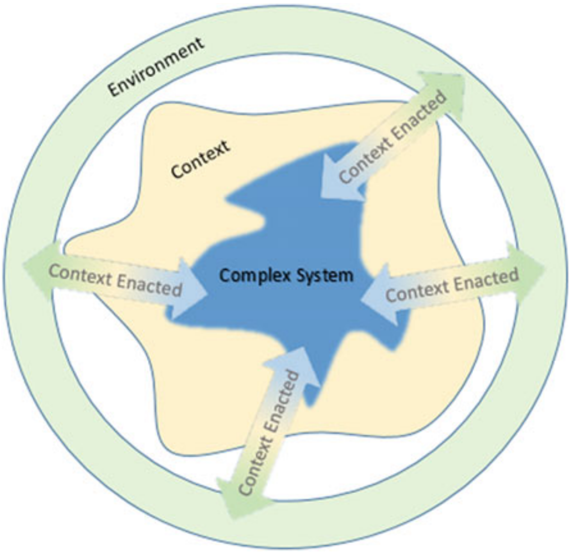

Fig. 2 Interaction of environment and context on a complex system

stakeholders and their understanding of the complex system but are only relevant when the stakeholders can articulate how the environmental element affects or is affected by the system or in some way contributes to the identity of the system. From an organizational perspective, Crownover describes the differentiation this way:

> 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 the context of the system of interest. Rather, the system context includes how the actions of the governance system enables or constrains the system in carrying out its purpose.

So, while we can describe the environment of a complex system, if we cannot articulate how an environmental element interacts with the complex system or provides meaning to the system identity, it is not a relevant contextual environmental element. This becomes very important when we are practicing CSG and conducting systems analysis on complex systems.

Defining and understanding system context appear easy at first since we have a tacit understanding based on our own individual perception. However, practitioners face the same realities when trying to define system context as they do with defining modern complex systems. Modern complex systems face uncertainty, interdependence, complexity, emergence, and ambiguity. A clean, perfect contextual framework of a given complex system is as impossible to articulate as a clean, perfect articulation of the given complex system. Table 1 defines these realities with respect to complex systems context.

Our understanding of the realities of complex systems and their contextual framework have evolved from systems theory and from a theoretical foundation for our understanding of context in CSG practice. Table 2 describes a core subset of relevant

Table 1 Complex system and complex system context realities

Reality	Definition	Understanding system context
Uncertainty	Incompatible knowledge casting doubt for decision/action consequences	Stakeholders have incompatible views on the contextual elements of a system, relevance of individual and aggregate contextual elements to the system governance and identity, degree of influence, and probability of influence on a complex system. The fact that complex systems themselves are uncertain exacerbated the already difficult task of finding a complimentary view of relevant context that is sufficient to ensure system viability and clarity of system identity
Interdependence	Mutual influence among systems, where the state of each system influences, and is influenced by, the state of interrelated systems	Contextual elements include enacted elements like organizational systems, political systems, environmental systems, social systems, and other systems that interact in ways that redefine how they influence and are influenced by a specific complex system. This interdependence adds complexity and variability causing drifts in the contextual framework that must be monitored and governed to minimize uncontrolled variability and negative impact on system identity
Complexity	System so intricate and dynamically interconnected that complete understanding, prediction, control, or explanation is impossible	Context is constantly changing and evolving and fundamentally defined by its interaction or relationship to the complex system. The complexity of the system, the contextual elements, and the varying perceptions and perspectives on system context make it impossible to have a complete understanding of contextual elements and how they influence and are influenced by the system and other contextual elements. This in turn makes accurate prediction, control, or explanation impossible
Emergence	Unpredictable events and system behaviors that cannot be predicted and are only known after they occur	Emergence happens in the contextual elements changing the enacted context of a complex system of interest forcing emergence in the complex system and potentially other areas of the contextual framework

(continued)

Table 1 (continued)

Reality	Definition	Understanding system context
Ambiguity	Lack of clarity in understanding/interpretation of both the system and context within which it exist	Ambiguity in the system of interest causes ambiguity in the understanding of the system's context. Additionally, context is an interpretation, which varies by individual, their ability to articulate, and their ability to have a clear understanding of context—which is nearly impossible

systems theory principles and how they apply to system context.[2] A more complete list can be found in Baugh, Bradley, Chesterman Jr., and Whitney's "Systems Theory as a Foundation for Governance of Complex Systems" [12]; Adams' "Systems Principles: Foundation for the SoSE Methodology" [1]; and Clemson's "Cybernetics: A New Management Tool" [5].

This theoretical understanding provides a foundation for Crownover's complex system contextual framework (CSCF) and a concept of complex system context as follows:

a. 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.
b. Complex system context includes an "enacted" environment, which captures system/environment interactions and interdependencies [11]. However, system context and system environment are conceptually distinguishable.
c. 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.
d. 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. The meaning and significance of context have to be contextualized within a specific situation, domain, discipline, or practice.
e. 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.

To help understand context in practical terms, W. B. Max Crownover used grounded theory methodologies to develop a framework [6]. The next section will review Crownover's complex system contextual framework (CSCG).

[2] Principles and description are quoted from Whitney, et al.'s *System Theory as a Foundation for Governance of Complex System* journal article [12].

Table 2 Systems theory principles and how they apply to system context

Principle	Description	Understanding system context
Boundary	The abstract, semipermeable perimeter of the system defines the components that make up the system, segregating them from environmental factors and may prevent or permit entry of matter, energy, and information	System boundaries are a necessary component to articulate a system's identity. System context helps to define boundaries by providing perspective and the ability to understand a system within its environment or setting. A CSG practitioner may set a system boundary of a software development project to include first line management, but not the CEO if the CEO is far removed from the project; or the project system boundary may include the CEO if the organization is small and the CEO is directly involved in projects. As context changes, the system boundaries should be reviewed, and conversely, when the boundaries change, the system contextual framework should be reviewed
Circular causality	An effect becomes a causative factor for future "effects," influencing them in a manner particularly subtle, variable, flexible, and with an endless number of possibilities	When something in the contextual framework of a system changes, it will affect the system. The effect of the change may in turn cause more system changes and further change the context of the system. Using the software project example of a complex system, if a project is developed in a company that is employee owned and then the company goes public, this contextual change may have significant impact on the project system. Employees may become less motivated and resistant to the change. This may cause communication problems and productivity problems. People may begin to turn over, and critical corporate knowledge may be lost resulting in restructuring the product or selling off that part of the company. Now the project system's context has changed. The effect becoming a causative factor for future effects may go on and on, affecting both system and context framework

(continued)

Table 2 (continued)

Principle	Description	Understanding system context
Complementarity	Two different perspectives or models about a system will reveal truths regarding the system that are neither entirely independent nor entirely compatible	System context is perceived by individuals and therefore interpreted and articulated in different ways. Each perspective adds information to build a contextual framework for a complex system and understand how the elements influence or are influenced by the system. For example, managers may help to establish organizational and leadership context while the financial analyst may provide fiscal and budgetary context. For the CSG practitioner, it is important to talk to stakeholders to build a complementary contextual framework that is satisfactory to all or critical stakeholders
Control	The process by means of which a whole entity retains its identity and/or performance under changing circumstances	System controls may cause contextual changes to steer a system toward a particular goal or to mitigate risk. For example, if the software team of our software project system is all over the age of 50 and a new 20-something hire joins the team to provide expertise in a new programming language, the CSG practitioner may prepare the team before the young developer joins by educating them on the generational differences and setting some new policies. In this way, the practitioner may mitigate negative consequences of a change to the system by adjusting the cultural contextual element

(continued)

Table 2 (continued)

Principle	Description	Understanding system context
Dynamic equilibrium	An entity exists as expressions of a pattern of processes of an ordered system of forces, undergoing fluxes and continuing flows of matter, energy and information in an equilibrium that is not static	Complex systems seek equilibrium. When something changes across the system and relevant system context, the forces will work for or against the change to bring the system back to what it knows as "normal." If change is desired, deliberate change management is required to create the "new normal." System context may effect unwanted change by implanting barriers or floodgates. Therefore, understanding the context of the system is important to ensure efficient system governance and change management
Holism	A system must be considered as a whole, rather than a sum of its parts	Holism cannot be achieved without the inclusion of context. To have a holistic understanding of a complex system, you have to understand the environment and how it influences the system. In our software project system example, to holistically understand the project system, you have to understand the stakeholder's role and influence on the system. The CEO may not be an internal component of the project system as he or she is far removed, however, the CEO may change the direction of the company away or toward the project product causing a reduction in force or the need to rapidly hire. While contextual elements may be external to the system, the enactment or how they influence and define the system is intrinsically part of the system and must be considered to avoid system failures

(continued)

Table 2 (continued)

Principle	Description	Understanding system context
Minimal critical specification	This principle has two aspects: negative and positive. The negative simply states that no more should be specified than is absolutely essential; the positive requires that we identify what is essential	Minimal critical specification applies to system context as well. If system context is defined with too many elements, it will take more resources to monitor and become overwhelming. If you define the system context too narrowly, you may miss a critical element and cause a type II error, missing the identification of a problem before it is too late, or a type III error, solving the wrong problem [4], because you have the problem source wrong as it was not identified in the system context definition
Purposive behavior	Purposive behavior is meant to denote that the act or behavior may be interpreted as directed to the attainment of a goal, i.e., to a final condition in which the behaving object reaches a definite correlation in time or in space with respect to another object or event	Governing a system through CSG and M5* (context) allows for system adjustments and changes that are purposeful and deliberate to meet desired goals and end states with some level of control over emerging system changes because the system and system context have been actively monitored
Requisite saliency	The factors that will be considered in a system design are seldom of equal importance. Instead, there is an underlying logic awaiting discovery in each system design that will reveal the significance of these factors	Complex system contextual elements and their impact on or by a system is understood relative to all other contextual elements. In this way, identifying elements with greater influence can focus monitoring and governing processes
Satisficing	The decision-making process whereby one chooses an option that is, while perhaps not optimal but good enough	Defining system context and identifying which elements are critical to deliberately monitor require satisficing. To achieve requisite saliency, the CSG practitioner must interview many stakeholders for a complementary perspective. Not all perceptions are the same, therefore a satisficing definition of system context must be the goal

3 Complex System Contextual Framework (CSCF)

The CSCF is the first contextual framework that can be used to guide a CSG practitioner to identify contextual elements and how they are enacted on a system. The CSCF is composed of categories, called meta-elements; sub-categories; elements; attributes; and dimensions. As research in CSG and contextual theory expands, other frameworks and methodologies may emerge. In the exercises for this chapter, you are encouraged to develop your own framework and apply it to a representative complex system.

The CSCF framework starts with four meta-elements: human, systemic, methodological, and environmental as described in Table 3. Meta-elements are a conceptual superset that logically group contextual elements.

The following hierarchies in Figs. 3, 4, 5, and 6 show the elements and attributes for each meta-element and are followed by a discussion of their applicability to complex systems and CSG.

The human meta-element recognizes the "human factor." Many people can recall an individual leader or team member that had a significant impact on a project or team. A leader can have a significant impact on a system as a decision maker. They can be good communicators, good decision makers, and morale building, or they can be confusing, poor decision makers, and morale draining. It is important to understand the stakeholders of a complex system, their roles, their level of influence, type of influence, how they are affected by other stakeholders, their relationships, the influence on and from relationships, their experience level in relevant areas, and their world views. This information is captured in the role-related sub-category and respective elements. It is also important to understand individually and at various group levels the culture, values, and relevant perspectives. Effective leaders take time to understand these factors before making major changes to an organization to ensure the most effective and least resistant path to success without collateral damage. As a CSG practitioner, these contextual elements are critical to effective governance and problem solving. The CSCF addresses these contextual elements in the perceptual sub-category of the human meta-element.

Table 3 Complex system contextual framework meta-elements

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

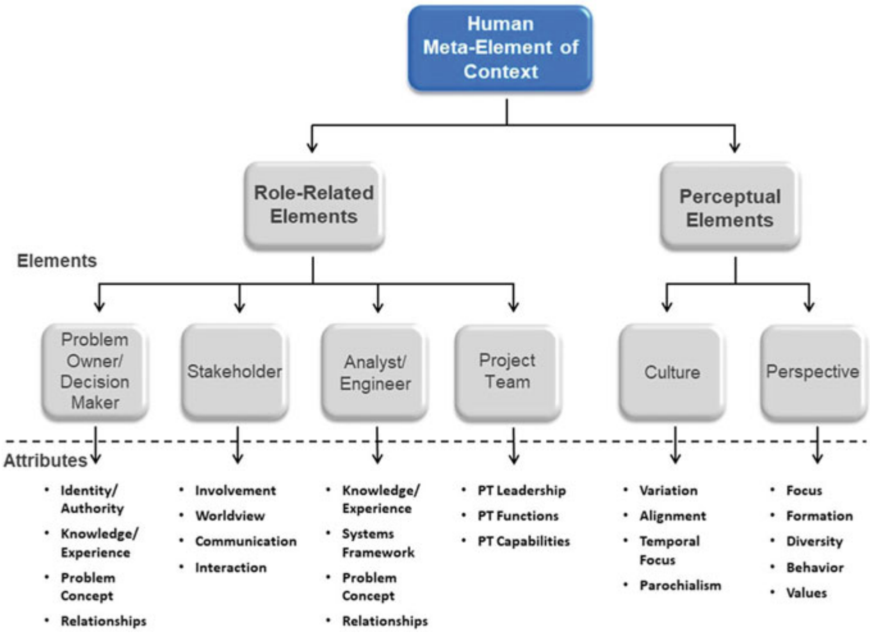

Fig. 3 Human meta-element—related to the various aspects of human involvement in complex systems, specifically looking at the roles people play and the perspectives they bring

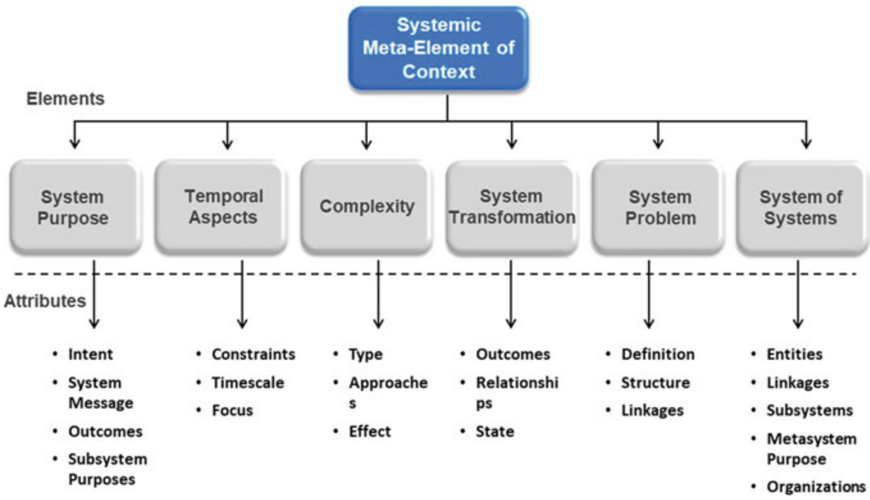

Fig. 4 Systemic meta-element—related to the various aspects of dealing with complex systems that stem from systemic principles and concepts and from taking a systems view

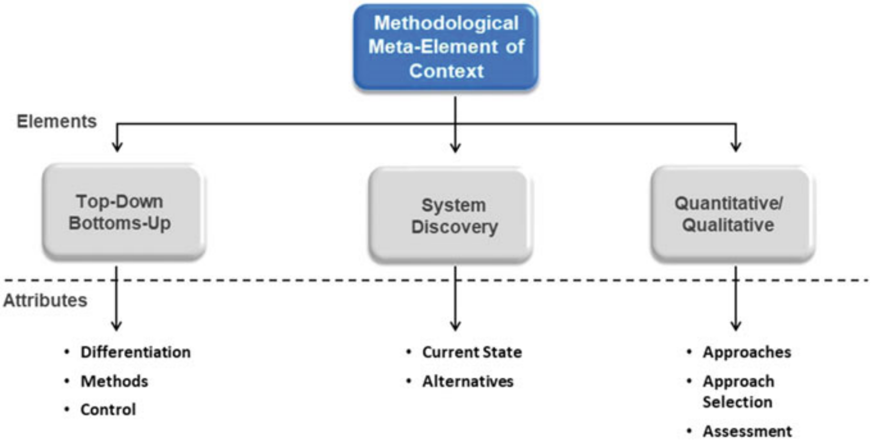

Fig. 5 Methodological meta-element—related to the aspects of dealing with complex systems that stem from specific approaches or methodologies being applied or considered for application

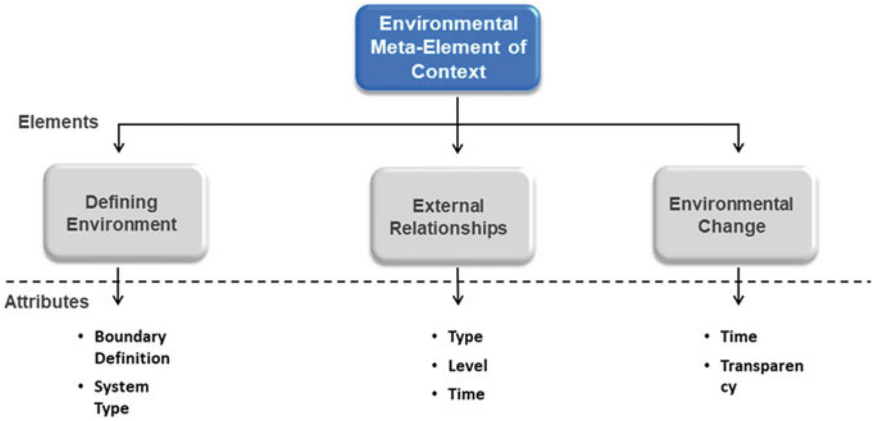

Fig. 6 Environmental meta-element—related to the aspects of dealing with complex systems that are related to the system's environment

The human meta-element category may be one of the most difficult for the CSG practitioner because people and relationships are complicated. If the practitioner assumes that policy and rules can be established and enforced to control people in a way that they do not have to take time to understand the contextual elements, attributes, and consequences on the system, they may incur a type III error in managing complex system problems. A type III error is when the wrong problem is solved precisely as described in part 2 of the chapter vignette.

A Context Vignette, Part 2—How Context Matters

In the chapter vignette, the organization had accepted a culture of high salaries for long hours *of work with an accepted high turnover rate of developers. When developers complained for long hours, they received bonuses making them temporally happy again. Leadership philosophy was that happy developers produce more code which produce more revenue. Unfortunately, they fail to see that the quality of the code was causing even larger losses in revenue and that very few of their developers where trained in software quality methodologies. The failure to understand and mitigate the experience level of both the owner-manager and the developers resulted in a decision to solve the wrong problem and the business began to fail.*

The systemic meta-element results from a recognition that a "system is affected because it is being viewed as and conceptually constructed as a system" [6]. This is particularly true when CSG practitioners are using CSG to govern a complex system. The CSG practitioner and systems analyst have their own experiences, perspectives on the system, varying levels of influence on the system, and values. A systems analyst with a high degree of CSG or systems thinking experience and inclination will have a different perspective and effect on the system than a systems analyst who does not.

The system analyst example exposes a link to the human meta-element. It is the perception of the stakeholders that either perceive or do not perceive the system as a system and agree or disagree on the system elements. When determining elements like the system's purpose, the worldview of stakeholders is required. Hopefully, there is a high degree of commonness or complementary views that provide a satisficing systems purpose statement. This is also true for the other elements: temporal aspects, complexity, system transformation, system problem, and system of systems representation.

Similar to the systemic meta-element, the methodological meta-system results from the recognition that the methodologies used to define, analyze, and govern a system also affect the system. These methodologies affect the system by producing resulting decisions, discussions, and actions. The tools and approaches can also affect the system during execution knowingly or inadvertently much like quantum particles whereby the very act of observing the particle affects the state. Additionally, this meta-system is also linked to the human meta-system. The human perspective determines the type of methodology to use and how it is used. It also determines if a methodology and the results are accepted and actionable. For example, if the systems analyst utilized a qualitative method, but the culture of the organization only recognizes quantitative methods, the analysis result may not be accepted by the organization.

Finally, the environmental meta-element captures the contextual elements most often thought of and discussed, but perhaps not in the way expected. This meta-element category does not give us a nice list of neat, tangible environmental elements to check off like political environment, socioeconomic environment, or physical setting; rather, it sets the stage to uniquely define environmental elements with salient influence on the system. "What is required is not simply a matter of providing a text-book 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" [6]. The defining environment element assists the practitioner to use a deliberate approach while recognizing that the approach itself may affect the system.

The external relationships element is where the practitioner uses the element attributes and dimensions to identify environmental elements (circumstances, factors, conditions, and patterns) that have a relationship with the system that may affect the system or be affected by the system. The element is labeled "external relationships" because the contextual element is not the building next door, but the knowledge that the building next door provides shade to my building thereby providing some level of cooling and a cheaper electric bill. A change in the external element will cause a change in my system. The focus on relationships also has the advantage of focusing CSG practitioners on relevant environmental elements.

The environmental change element of the environmental meta-element addresses "the importance of the system having awareness of and being able to respond to environmental change" [6]. To effectively analyze and govern a system, it is imperative to understand how the system responds to internal and external change. Change management requires a human, system, methodological, and environmental contextual intelligence for success.

4 Context in Practice

This section will use the systems of systems engineering (SoSE) methodology as described in Keating and Adams, *Overview of the systems of systems engineering methodology* [2] in the International Journal Systems of System Engineering, to provide a representative practical application that may be use in CSG. The SoSE methodology, as shown in Fig. 7, is built from foundational systems principles and

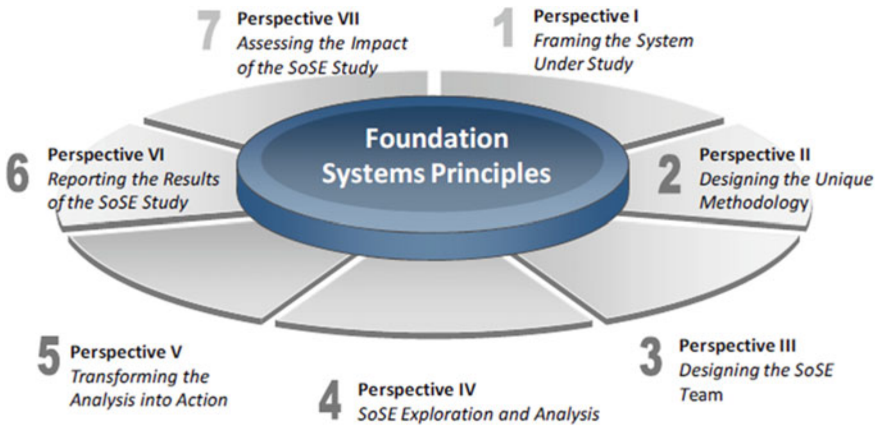

Fig. 7 System of system engineering methodology

seven perspectives. It can be used to address complex system problems or to establish a framework for persistent governance.

In Table 2 of this chapter, we discussed a core set of system principles that are foundational to the SoSE methodology. Here we will provide a short overview of the seven perspectives of the SoSE methodology followed by a more comprehensive discussion of perspective I. By framing the system under study in perspective I, we will show how the practitioner may build the contextual framework for a system. This framework can be used for system governance or problem solving.

[3]*Perspective I, Framing the system under study*

This perspective is designed to rigorously structure the system problem, the contextual setting and environment within which the problem system exists. Key execution elements in this perspective include.

1. Identify the wide context for the system under study—establish the circumstances, factors, conditions, and patterns that characterize the situation surrounding the SoS at a high level.
2. Characterize the system under study—understand the basic structure and characteristics of the SoS under study, including the SoS's objectives, functions, environment, resources, components, and management.
3. Characterize the complex nature of the system domain under study—establish the complex nature of the SoS and problem domain.
4. Present the system domain as characteristically complex—present the SoS under study as a complex systems problem.
5. Frame the SoSE problem—depict the problem situation by expressing the structure, elements of processes, and the situation.
6. Define study purpose, reformulated problem statements and objectives—clearly explain the nature, purpose, high-level approach, and objectives for the effort.
7. Conduct stakeholder analysis—explicitly account for and address the multiple interests (rational and irrational, inside and outside) which can impact achievement of system objectives.
8. Conduct contextual analysis—account for the set of circumstances, factors, conditions, values, and/or patterns that are influential in constraining and enabling the SoS engineering process, the SoS solution/recommendation design, SoS solution/ recommendation deployment considerations, and interpretation of outputs/outcomes stemming from the effort.

Perspective 2 Designing the unique methodology

This perspective designs a unique methodology based on the problem and the problem context.

9. Construct high-level design for the study—construct a unique high-level methodology that will adequately support the study objectives and the SoS context. Must be compatible with the problem and problem context.

[3] Perspective overview taken from [2].

10. Develop the analytic strategy—create the design for quantitative and qualitative exploration (data collection and analysis) necessary to understand and make decisions concerning the SoS under study.
11. Develop assessment criteria and plan—construct a set of measurable criteria to be used during and after the problem study to ensure continued fit of problem, context, methodology, and capability to meet study objectives.

Perspective 3 Designing the SoSE team

This perspective designs the team to undertake the SoSE study, taking into account the nature of the SoS problem and the team resources, skills, and knowledge that can be brought to bear for the problem.

12. Assess team knowledge, skills, and abilities (KSA)—develop an inventory of team knowledge, skills, and abilities that may be used in the study.
13. Match team KSA to the analytic strategy and unique methodology—based on the KSAs, establish assignments, roles, and expectations for the team in performing the study. Team expectations and selection of task leaders are established.
14. Establish means of team expectation and performance assessment—construct a set of measurable criteria that can be used during and after the SoS problem study to evaluate the performance of the team.

Perspective 4 SoSE exploration and analysis

This perspective is designed to explore and conduct the emergent analysis by executing the analytic strategy and SoSE management plan (SoSEMP). Its constituents include.

15. Build the SoSE management plan (SoSEMP)—the SoSEMP defines how the SoS study will be organized, the structure of the team, and how the SoSE process will be designed to provide products that directly support the study goals and objectives requirements.
16. SoSE exploration and analysis—explore and analyze each study objective by executing the analytic strategy.

Perspective 5 Transforming the analysis into action

This perspective is designed to transform the results of the emergent analysis by guiding implementation of derived recommendations. Its constituents include.

17. Define implementation goals, objectives, and activities—clearly explain the nature of the implementation, purpose, high-level approach, and objectives necessary to support the desired SoS outputs and outcomes.
18. Modify the SoSE management plan (SoSEMP)—add activities to the integrated schedule that ensures that the tasks from the implementation objectives tree are properly resourced to support the implementation goals, objectives, and activities.

19. Implementation of the exploration and analysis recommendations—change, modify, or construct processes for the SoS under study to implement recommendations.

Perspective 6 Reporting the results of the SoSE study

This perspective reports the results of the SoSE effort to capture the transformation of the analysis into action. It comprises.

20. Developing the engineering report—develop a coherent set of artifacts (data, analyses, correlations, etc.) that can provide specific findings and recommendations that directly impact the SoS problem under study.
21. Internal evaluation of the engineering report—evaluate the study report using the set of measurable performance criteria previously developed.

Perspective 7 Assessing the impact of the SoSE study.

This perspective is designed to assess the impact of the report on the real-world SoS problem under study. The final two of the 23 perspective-related elements are assigned here, and they are

22. Evaluating the initial impact of the engineering report—evaluate the impact that the SoSE study report had on the real-world system problem and its environment.
23. Plan for follow-up and follow-through—evaluate the impact analysis and develop a set of actions to follow-up and follow-through on the analysis.

In perspective 1, we identify key contextual elements and their potential impact on the system. These contextual elements should be reviewed and considered in all following perspectives and actions. They will likely evolve as the practitioner continues to advance their understanding of the system. When changes are made to the system contextual understanding, a retroactive look at completed tasks should be reviewed and modified if the advanced systems context understanding warrants.

Perspective 1 has eight elements as described above. The first element, identification of the wide context for the system under study, establishes the importance of context from the very beginning. “Engineers must understand and ultimately represent context if they are to move a system or SoS of interest from some current state to a different, desired state” [3]. “Complex systems cannot be understood independent of the context within which they exist” [3].

In the beginning, there exists a tacit knowledge of the complex system under study which is not unanimously shared by all stakeholders. Sometimes the framing effort has a problem statement if the effort is to solve a complex system problem; and sometimes a set of disparate documents exist that contain elements of a system description, like a contract vehicle, vision statement, engineering design document, or software development plan. Either way, the first step is to establish a problem statement or basic system description. A system description should be a short description of the complex system including goals for management and desired outputs and outcomes.

These statements should be reviewed and updated by all key stakeholders, producing a complimentary and satisficing statement.[4] With this very basic understanding of the system and effort, element 1 of the perspective 1, developing the wide context, may begin.

The output of this effort, and subsequent contextual analysis efforts, will be called the system's contextual framework. The practitioner may establish the system's contextual framework in many ways. A recommended approach that is encouraged to be tailored and modified to the benefit of the effort and stakeholders understanding will be used as a representative approach.

One way to capture the system's contextual framework is to develop a matrix with the columns identified in the contextual matrix, Table 4, and the contextual elements identified in the rows. Use Crownover's CSCF, [6] the established problem or system description statement, and the factors in the table to guide the first pass population of the matrix. In each subsequent perspective element, this matrix should be reviewed and updated as new information is discovered. The practitioner should interview as many stakeholders and experts as possible to ensure a complimentary matrix solution.

As the matrix is developed, the practitioner may begin to form or confirm system boundaries. Contextual elements may be internal, external, and boundary crossing, but in order to understand the impact to the system under study, the practitioner has to have an understanding of what is part of the system and what is part of the system environment (external). Generally, something is internal to the system if it can be managed and governed through adjusting system controls. For example, usually federal laws and regulations are considered external contextual elements, but company and department policies may be internal to the system. However, remember that complex systems will always have ambiguity and uncertainty, so do not expect perfection. A minimal critical specification is the goal. The practitioner should consider as much as can be identified but focus on the most important and impactful elements.

Element 2 of perspective 1, characterize the system under study, will use the problem/initial statement and the system's contextual framework developed in element 1 as an input to develop a list of system characteristics including the systems definition, components, objectives, functions, environment, resources, and governance structure. The systemic meta-element elements, system purpose, temporal aspects, complexity, system transformation, system problem, and system of systems, should be considered in the holistic characterization. The contextual framework matrix may be used for the system environment characteristic of element 2. The expression of the environment characteristic (external to the system, but a change in the element will cause a change in the system) is the meta-element section rows of the matrix. Similarly, the human meta-element rows should contain and/or be updated

[4] If the world views of stakeholders are so different that a satisficing statement cannot be written, a type four error has occurred. A type four error is engaging in a problem solution with incompatible or divergent "philosophical" perspectives. These efforts do not often end well unless the opposing philosophical perspectives are addressed satisfactorily.

Table 4 Contextual matrix

Column	Description	Factors
Element number	A number to uniquely identify each row	
Element name	A short name of the contextual element that uniquely identifies it and gives a basic understanding of what it is or how it affects the system	
Element description	Describe the element with enough detail that the reader can understand the element, how it is unique, and the data captured in the rest of the columns	
Meta-element	The primary CSCF meta-element category of the element described in this row	The practitioner should identify if this row element is a result of a specific meta-element or the interaction of meta-elements elements
Element type	The element type may be the CSCF attribute or some other designation (like circumstance, factors, conditions, values, or patterns) that allows the practitioner to logically group the elements in a useful way	This column should aid the practitioner in quickly identifying which rows need to be updated in subsequent passes of analysis. It also should facilitate the risk matrix and mitigation process
Influence/impact on the system	What effect does this row element have on the system? What is the interaction with the system and other contextual elements?	Consider how this row element may influence or impact the system should something change in the system or the row element. Understanding the influence of this row element includes both current influence and how changes may influence
Factors required for influence/impact	What are the factors of this row element that are required to happen or exist to influence the system as discussed in the previous field (influence/impact on the system)? Factors should be identified as factors for current, steady-state influence, and factors of change	The practitioner should consider other contextual elements, system changes, row element changes, or events. This field should help the practitioner identify what must be monitored to effectively govern the system

(continued)

Table 4 (continued)

Column	Description	Factors
Type of impact	How does the current, steady-state factor affect the system? If one or more of the change factors for influence of the row element happens, how is the system or other contextual items expected to be affected?	Tools like SWOT (strengths, weaknesses, opportunities, and threats) analysis can help the practitioner to more completely understand the impact. Impact may be an opportunity, or it may be a threat that is realized by the strengths and weaknesses of the contextual elements' influence on the system
Probability of occurrence	This field does not consider the current, steady-state influence of the row element on the system. It should show the likeliness of opportunity or risk identified in the previous column (type of impact) should one of the factors of change happen?	This may be quantifiable or qualitative
Severity of occurrence	This field does not consider the current, steady-state influence of the row element on the system. It should show the severity of impact on the system from the changes factors if they were to occur	Severity is not bad or good, it is a variable of degree. A change may affect every sub-component of the system such that it changes the very identity of the system or it may only change one part of a sub-system that has minimal influence The practitioner should consider compounding influence in this field. Many times a simple change causes another change which causes other changes, aggregating to a much higher overall impact on the system
Control mechanisms	What mechanism can be put in place to control changes, mitigate risks, or influence changes?	In addition to considering the risk management control mechanisms, consider that system steady state is not always desired. When change is desired, how can the practitioner use this row element to facilitate or instigate while controlling for a particular outcome?
Level of control	Based on the influence and impact of this row element, should the practitioner monitor closely or is periodic assessment sufficient?	The practitioner should consider what is required to maintain steady state, and what is required for change when populating this field

by the governance structure characteristic definition. The process to define system resources will likely identify, clarify, and/or update internal and external contextual elements in the contextual framework as well. For example, military technology development programs have to operate within the federal government appropriation cycle and rules. If an appropriation bill is not passed at the beginning of the fiscal year, many programs are directly affected. This is an external contextual element that is very important to the system.

This step will identify sub-systems and internal contextual elements as each sub-system exists within its own context. The practitioner may want to add a column to the contextual framework matrix to relate the contextual element row to the system or one of its sub-systems and an associated column to describe the relationship with other sub-systems, the super-system, or the external environment. Again, there are many contextual elements, so focus on the elements that have the most impact on the system or the most potential to impact the system if altered.

The characteristics that describe the complex nature of the system and the complex domain of the system under study are the subject of elements 3 and 4 of perspective 1. Understanding the complexity of the system is directly related to the complexity of the response required to govern or affect change in a system. The systems theory and CSG law of requisite variety states that “control can be obtained only if the variety of the controller is at least as great as the variety of the situation to be controlled” [12]. Therefore, a careful assessment of the complex system characteristics is expected to update the contextual framework control mechanism at the very least.

The characteristics of complex systems are related to the meta-elements in the contextual framework matrix as described in Table 5. This table should help the practitioner understand the characteristics and how to use the CSCF to assess the complex system.

In element 5, a rich diagram is constructed to describe the complex system. It may not directly represent the context of the system as described in the matrix; that is okay. However, the practitioner may want to add a column to the contextual framework matrix that maps elements onto the system diagram for reference.

Element 6 of perspective 1 relooks at the problem statement or system initial description system and objectives to refine them based on the analysis of previous elements. The contextual framework matrix is both an input and an output of this element as the systemic meta-element rows may evolve now that there is a deeper, holistic understanding of the system and its context.

The human meta-element rows in the system context framework matrix should make short work of element 7 of the perspective 1 and conduct stakeholder analysis. At this point in the process, the practitioner is taking another look with a focus on the stakeholders. Adams and Meyers offer several characteristics and tools for a thorough analysis of stakeholders in Adams and Meyers [3]. The practitioner should update the matrix with any revelations.

Element 8 of perspective 1, conduct contextual analysis, takes one more pass at contextual framework matrix now that the framing of the system is almost complete. This step focuses on identifying and understanding the contextual elements impact

Table 5 Complex system characteristics relation to CSCF meta-elements[5]

Characteristic	Description	Metasystem relationship
Hyper-turbulent conditions	A complex system is said to exhibit hyper-turbulent conditions when the environment of the problem is highly dynamic, uncertain, and rapidly changing	The temporal aspects of the systemic meta-element address the rate of change and the agility for change. The practitioner should evaluate the level of turbulence in the system and how contextual elements may affect the turbulence
Ill-defined problems	A complex system problem is ill-defined when circumstances and conditions surrounding the problem are potentially in dispute, not readily accessible, or lack sufficient consensus	The system problem element of the systemic meta-element attributes definition, structure, and linkages describes the contextual elements respective to the problem definition. The methodological meta-element addresses the contextual elements analysis methodology. The practitioner needs to consider how the ill-defined nature of the system and problem affects the system and the governance or problem-solving methodology
Contextual dominance	In complex systems, the technical aspects of the problem are overshadowed by the contextual or soft aspects	Practitioners often attempt to solve system problems with technical solutions that do not work because of contextual impact like human factors. The contextual matrix developed in the process outlined in this chapter should define the contextual element, their relative system impact, and the severity of the impact which can be defined as the element's dominance. The methodological meta-element assigns contextual elements to how we recognize and use this information in the analytical process

(continued)

[5] Descriptions in this table are quoted from Adams and Meyers "Perspective 1 of the SoSE methodology: framing the system under study". [3]

Table 5 (continued)

Characteristic	Description	Metasystem relationship
Uncertain approach	There is no clear or prescribed approach to proceed with the SoSE effort that guarantees success. Standard processes applied to the ill-defined problem have failed or are likely to fail to resolve the issue	The methodological meta-element reviews the contextual elements associated with the analytical methods used to define and solve complex system problems. Since the approach taken is uncertain, effects of errors on the system and the methodology processes should be considered
Ambiguous expectations and objectives	A complex system cannot be perfectly defined and understood the same way by stakeholders; therefore, ambiguous expectations and objectives may result	The elements of the systemic meta-element and the perceptual elements in the human metasystems are the predominant linkage to the CSCF; however, the effect or relationships with all other elements and metasystems describe ambiguity of expectations and objectives
Excessive complexity	A complex system often has excessive complexity such that traditional approaches are not adequate for management	This characteristic may use the complexity attributes of the systemic meta-element to assess the excessiveness and the system effects
Pluralistic perspectives	Complex systems have a high degree of variability of individual perspectives, objectives, and perceived interests. Stakeholders are not expected to identify the boundaries of a system or the system problem the same way	The perceptual elements in the human metasystems are the predominant linkage to the CSCF; however, the effect or relationships with elements of the systemic, methodological, and environmental metasystems are also critical to understanding the system context
Extended stakeholders	Complex system stakeholders include extended stakeholders like those that emerge throughout the life of the system, environment contextual stakeholders, and the CSG practitioner in addition to the traditional stakeholders	The human meta-element and the external relationships of the environmental meta-element describe the extended stakeholders and their relationship to the system or to the relevant environment, but a review of relationships with the systemic and methodological meta-elements may uncover not so obvious stakeholders

(continued)

Table 5 (continued)

Characteristic	Description	Metasystem relationship
Emergence	Complex systems experience emergence—the occurrence of events and system behaviors that result from interactions between system elements cannot be predicted and are only known after they occur [9]	Characterization of emergence in the contextual framework is difficult. A review of the systemic meta-element and its relationships with the human and environmental meta-elements with respect to elements, attributes, and dimensions that may contribute to excessive emergence or system stabilization may reveal important information for the contextual framework
Ambiguous boundaries	The inclusion and exclusion boundary criteria are arbitrary and necessarily qualitative in nature	The systemic and environmental meta-elements help to shape the understanding of system boundaries. In the methodology meta-element, the ability of the methodology to develop complimentary system boundaries and at the same time recognize the imperfection of their declaration will have contextual relevance to the system
Unstable planning foundations	The complex, ill-defined, and turbulent nature of complex systems makes efforts to plan specific engineering or analysis efforts subject to sudden, and potentially radical, shifts	This characteristic provides an important consideration for the examination of the methodological meta-element
Information saturation	There is too much data and information to understand a complex system holistically. It is challenging to sort through the information and achieve requisite saliency	This characteristic is applicable to all meta-elements. Recognizing that perfection is not possible, and that there is too much information, requisite saliency is required

(continued)

Table 5 (continued)

Characteristic	Description	Metasystem relationship
Identity coherence	Identity is the set of fundamental values, patterns, and attributes that provides a consistent reference point and baseline logic for making grounded decisions, taking consistent actions, and providing self-reinforcing interpretation of abstract events. Modern technical enterprises are confronted with an accelerating pace, blurring of ethical value systems, and complexity. Incoherent or ambiguous identity deepens the inability to achieve consistency in the face of the new realities facing organizations working on complex SoSE problems	In the methodological meta-element review, it is important to make sure that all, or the right stakeholder, have been interviewed in the system definition and framing process to provide a complimentary and satisficing statement of identity which includes elements of the system meta-element
Large number of systems elements	Complex systems have a high degree of variety in system elements. System elements are simply parts or components of the system and are unlimited in variety	While it is impossible to define every element of a system, the systemic meta-elements of a system are a starting point. However, the real importance of this characteristic is the understanding that requisite saliency is necessary and a good representation of a system is better than none
Interaction between systems elements	The interactions between system parts, referred to as relationships, are critical to framing the system as they govern the properties of the system	The system of systems and systems transformation elements of the systemic meta-element; the external relationships element of the environmental meta-element; and the role-related elements of the human meta-element directly address relationships. The practitioner should review system and sub-system interactions and contextual element interactions

(continued)

Table 5 (continued)

Characteristic	Description	Metasystem relationship
Predetermined attributes	Many system attributes are predetermined from the independent, purposefully designed, acquired, and managed sub-systems from which they are constructed	The sub-system purpose attribute of the system purpose element and the system of systems element of the systemic meta-element should provide the practitioner with an understanding of the predetermined attributes of the system
System evolution over time	Does the system change over time or is it a static system? Complex systems change over time	The temporal aspects, complexity, and system transformation elements of the systemic meta-element address how the system may change and respond to changes over time, but should be reviewed with the environmental change and external relationships element of the environmental meta-element and the human meta-element
Sub-systems pursue own goals	Sub-systems have been designed to operate independently such that each sub-system has a purposive objective or behavior and is a producer of some end result, objective, or goal. A natural tension between the connectedness required for operation within the complex system and autonomy required to meet the goals and objectives of its own operations will exist. How do the sub-systems and the resulting tensions affect the complex system?	The sub-system purposes attribute of the system purpose element, and the system of systems element of the systemic meta-element should provide the practitioner with an understanding of the sub-system goals and how they impact the larger system as well as the environment

(continued)

Table 5 (continued)

Characteristic	Description	Metasystem relationship
Predominantly open to environment	Complex systems are affected by their environment and are, in a way, a sub-system, to even larger complex systems	This characteristic speaks directly to the environmental meta-element and helps the practitioner to understand that not only do the environmental elements affect the system, but the system affects the larger systems embedded in the environment. There is an important interconnectedness which is the foundation of holistic systems thinking
Interaction organization	Most complex systems are part of other larger systems and themselves contain sub-systems. The concept of hierarchy recognizes the openness of the system and relationship to its environment from an interdependent perspective	Similar to the factors discussed in the "predominantly open to environment" row of this table, this characteristic articulates the notion that the system under study is a sub-system to larger systems and is therefore embedded in a bigger hierarchy. This means that the practitioner should consider how the system under study may be affected by the contextual elements of larger systems in its environment. However, remember the concept of requisite saliency and bound the review to areas of greatest importance
System affected by behavioral influences	Complex systems are routinely affected by the behavioral influence from the systems environment	A review of the behavior of contextual elements in the human, methodological, and environmental element is applicable. The behavior of an environmental system like a political system is as important to understand as the behavior of leaders who operate within the system and have a direct influence on the system

on the system and scoping the matrix to a minimal critical specification. The practitioner should review the influence on the system, factors for influence, impact, probability of occurrence, severity of occurrence, control mechanisms, and level of control columns in correlation to the refined system framing outputs. This review is the last step in the perspective 1 process before a brief exercise is designed to help the practitioner understand the implications of the outputs created in perspective 1 of this methodology.

In the final exercise of perspective 1, the practitioner is asked to examine the implications for the system under study, the organization conducting the analysis, the individuals conducting the analysis, and the SoSE discipline. While this step is not required, it is encouraged for CSG practitioners. As CSG is still young, reflection and feedback will help future practitioners.

Once the complex system's contextual framework matrix has been developed with respect to the system framing, stakeholders who seek to govern the system to maintain an identity and achieve a desired goal or solve system problems should monitor contextual elements with periodic assessments. As risks are realized, the matrix control mechanisms may be used to mitigate negative impacts or enhance positive impact. If a change in the system's identity, purpose, or goals is desired, the matrix can be used to identify areas to stimulate change with minimal negative consequences. The matrix should continually be updated as all complex systems evolve and change.

5 Implications of Context in Complex System Governance

In this chapter, we defined complex system context with respect to CSG, a framework to help identify system context, and a methodology to frame a system in preparation for solving system problems or to actively govern. The framework and methodology were representative and can be modified or adapted as required. It is recommended and encouraged for the practitioner to find the approach that works best for the specific effort. However, a holistic approach should not be abbreviated to focus only on the quantifiable, "low-hanging fruit" contextual assessment. Contextual influences directly affect the identity and viability of the system. Many practitioners are uncomfortable identifying human-based influences on a system, but they cannot be ignored as they often have the most influence.

Context can be very difficult to articulate, and no perfect solutions are possible. "There's no way to map every single factor in even a simple real-world environment, but it's possible to take snapshots from different perspectives, at various key moments, and bring them together into something more like a collage of snapshots that come nearer to telling the entire story" [7]. However, if the importance of understanding a system in context, and all the contextual factors that may influence a system, is recognized, the practitioner will have a higher probability of success meeting their goals.

The knowledge and tools discussed in this chapter are designed to help the practitioner achieve the greatest success possible. However, there remains plenty of room for further research in the area. It would be ideal if an easy-to-use model and method for identifying critical contextual items and a system for monitoring, assessing, and governing those critical items existed. Tools like checklists, measures of effectiveness, mitigation techniques, and rules for what is critical and what is not would make a new practitioner more effective and faster. The exercise section of this chapter will challenge you to try and develop these tools for a specific system. After the exercise, consider how the solutions can be applied generically across all complex systems.

Exercises

1. From your experience, select a complex system and use the methodology in this chapter to frame the system context. For this initial familiarization exercise, multiple stakeholder perspectives are not required. It should be completed by the practitioner only.
    a. Did you discover areas of context that were not obvious to you before you started?
    b. How did this exercise help you understand the system under study?
    c. How could this process be improved or modified to better accommodate the analysis of the complex system selected for this exercise?
2. Develop a set of categories, like a checklist, for practitioners to consider to describe the environmental complex system contextual items.
    a. How will this checklist help the practitioner?
    b. When would these categories not work for a practitioner?
    c. When you need to make decisions, do you consider all of these categories? Explain your answer.
3. Using the complex system contextual framework (CSCF) described in this chapter, explain how elements from different metasystems interact. Select three separate examples for this exercise.
    a. How might these interactions affect the system?
    b. Describe how this examination of element interactions would modify your response to exercise 1?

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