Future Challenges for Complex System Governance Research and Practice

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Abstract This chapter provides an overview of the current state of the CSG field, including achievements, future challenges, and developmental directions. CSG is introduced as an evolution and distinction from System of Systems Engineering. Following the introduction, four primary areas of exploration are examined. First, a summary of the current state of the CSG Field is conducted. The current state of the field is critiqued with respect to what has been accomplished as well as present shortcomings. Second, advancement challenges across the spectrum of theoretical/conceptual, application, and supporting methods/tools/techniques are examined. Third, the future development of the CSG Field as '*the system-science based engineering of technologies for application to improve design, execution, and development of complex systems*' is explored. Fourth, major points of consideration for advancing practice of CSG is examined. The chapter concludes with a set of exercises to examine critical issues in the design, execution, and evolution of systems using CSG.

Keywords CSG field · Development challenges · Future directions

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1 Introduction

Complex system governance (CSG) is an emerging field that traces its formal introduction to 2014 in an article titled *Complex system governance: concept, challenges, and emerging research* [55]. However, the seeds for CSG were sown well before the 2014 formal introduction. The formation of the National Centers for System of Systems Engineering (NCSoSE) at Old Dominion University in 2003 focused on understanding the issues related to integration of multiple complex systems. The launching of the Center coincided with the first article titled *System of Systems Engineering* [65]. In this article, System of Systems Engineering (SoSE) was defined as "The design, deployment, operation, and transformation of higher-level metasystems that must function as an integrated complex system to produce desirable results." [65, p. 41]. This early work, coupled with the evolution of the work at the Center, set in motion seven important evolutionary distinctions of CSG from SoSE (Fig. 1). First, the concept of 'metasystem' was introduced from the Management Cybernetics field [5–7]. The metasystem is a set of functions and corresponding communications channels that act to provide for control and communication in a system. The metasystem became a central construct for CSG. The metasystem, and the management cybernetics from which it emanated, followed through to the current instantiation of the CSG Reference Model and emerging CSG field.

A second pivotal developmental theme for CSG stemmed from the conclusion that the systems of interest for System of Systems Engineering (SoSE) were too complex to take a *'technology first, technology only'* approach to the development of systems

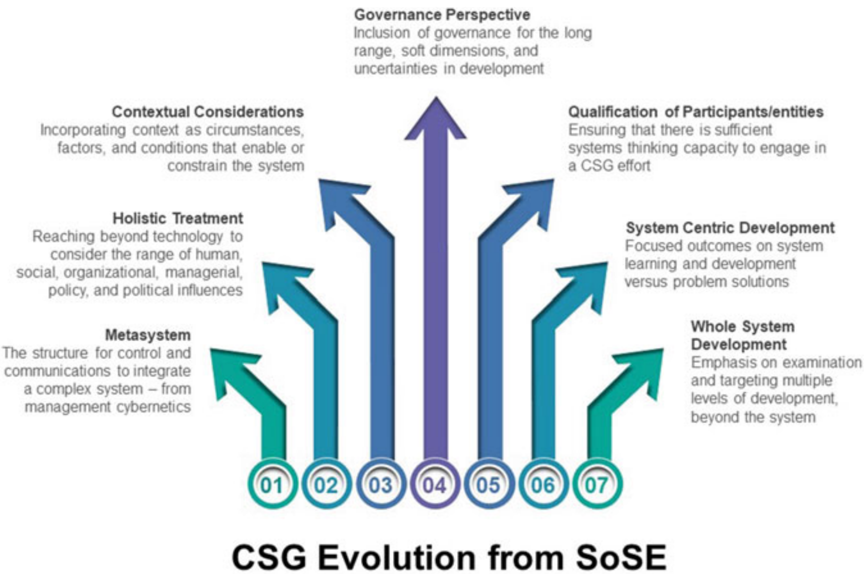

Fig. 1 Distinguishing CSG from SoSE

of systems. Instead, the work of the Center was grounded in the underlying '*holism*' suggested by systems theory, a perspective that was not embraced by the dominant SoSE community at the time and not fully understood. Grounding in systems theory and management cybernetics invoked taking a systems view and the inclusion of the range of technological, human, social, organizational, managerial, policy, and political dimensions into account for the SoSE problem space. The consideration of the holistic range of dimensions for SoSE moved beyond the *'technology first, technology only'* (e.g., technical interoperability) approaches that had dominated the early development of the SoSE field. This is not intended to disparage in any way the early work in the SoSE field focused on technology integration. This was necessary early in the instantiation of SoSE and still remains essential today. However, the exclusive view of the SoSE problem space as fundamentally technology-oriented has diminished the projection of the field to more complex 'holistic' problem spaces. Also, engaging a holistic-based paradigm required that a systemic world-view, grounded in the underlying systems theory (the paradigm and doctrine that are based in systems science) would be necessary to advance SoSE. Unfortunately, the prevailing perspectives of SoSE at the time viewed SoSE as an extension of Systems Engineering, thus requiring a reductionist mindset. This mindset required linear thinking, tightly bounded problems, objective definition, repeatable application of proven methods/tools, and seeking optimal solutions. Unfortunately, the reductionist mindset continues to show limitations when cast against the emerging holistic problem domains that are the hallmark of modern systems (e.g., health care, cybersecurity, Internet of Things, etc.). Thus, CSG emerged as a response to take a more holistic approach to the complex problem domain characteristic of the state of complex systems (of systems) and their constituent problems.

A third primary distinction sought by CSG was in the appreciation of 'context'. Context is taken as the set of circumstances, conditions, factors, trends, or patterns within which a system of interest is embedded. The separation of a system from its context for the convenience of analysis is a false separation. For example, such contextual factors as resources, power, politics, support infrastructure, and leadership style can play a substantial role in determining system performance. Absent an emphasis on context is considered incomplete framing for a complex system. The result is to create the conditions for committing a Type III Error [64], or solving the wrong problem in the most efficient way possible. Holistic framing was deemed essential to taking both system and context into consideration, as well as the interaction effects for CSG. Additionally, the wider inclusion of context introduced the appreciation of 'soft' (human, social, organizational, managerial, political, and policy) aspects of complex system development. This was in addition to the traditional 'hard' (technical/technology) aspects of development. The inclusion of 'soft' dimensions in the 'analytical SoSE space' was in contrast to prevailing mindsets in SoSE that were focused almost exclusively on the 'hard' aspect of complex SoSE. Thus, CSG was in search of an alternate paradigm, grounded in the conceptual/theoretical foundations of systems theory (the axioms and propositions that explain and provide understanding of complex system structure, behavior, and performance) and management cybernetics (the science of effective system structural organization).

A fourth distinction in CSG was the incorporation of system governance as the third conceptual underpinning to provide completeness in CSG. The system governance field helped to: (1) add an important dimension to the communication and control perspectives provided by management cybernetics, (2) engage more readily in the higher-level perspectives of establishing direction, oversight, and accountability, including 'soft' dimensions, to supplement management cybernetics, and (3) projected the 'long view' and 'fuzziness' that characterize the governance field. The intersection of management cybernetics, systems theory, and system governance provided the conceptual/theoretical foundations upon which the emerging CSG paradigm could draw. This allowed for a departure from more restrictive instantiations of SoSE.

A fifth distinction sought in separation of CSG from SoSE was found in the qualification of both participants and entities to appropriately engage the approach. Application of SoSE, as well as other systems-based methodologies (for examples see [27]) had no qualification of preparedness of individuals or the system having necessary prerequisites to effectively apply the approach. The remedy for this shortcoming in SoSE formulations was found in the CSG mandates to: (1) establish the degree of systemic thinking capacity, held by individuals and the system of interest, available to deploy CSG from a compatible systemic mindset essential to success, and (2) understanding the current state of CSG for the system to determine the types of feasible strategies/actions/initiatives that might be pursued with confidence in the probability of being successful. Thus, CSG was born of a need to separate from SoSE formulations that did not qualify either individuals or the system capacity to effectively engage the approach.

A sixth distinction of the CSG separation from SoSE had to do with the *expectations* for engaging in an endeavor. SoSE applications were primarily driven as problem-focused approaches with solution-driven expectations. At a tacit level, this mindset requires the narrow bounding of the 'problem' as opposed to the 'holistic system of systems' as the focus. The result is the engagement of SoSE as problem-centric, versus SoS-centric, in search of solutions to well-bounded problems or decision support. In contrast, CSG is targeted to system development, not whole system solutions to narrowly prescribed problems. However unsatisfying this might be to traditional SoSE perspectives, CSG is targeted to accomplishment of several different potential opportunities for system development, including: (1) development of individuals and the entity to engage in higher levels of systemic thinking, not only about the system in focus, but also with collateral extensions to other systems, issues, and contexts, (2) identification of system support infrastructure as a source that can be both enabling and disabling and targeted for development from a CSG effort, (3) the development of the system of interest across design, execution, and developmental improvement areas discovered as feasible to address, (4) identification of aspects of the 'larger system/organization/enterprise' that are in need of adjustment to more properly support the system of interest, (5) the assessment and accounting of contextual aspects for the system of interest that have a positive/negative impact on the performance of the system of interest and can be addressed within the scope of the CSG endeavor, and (6) determination of environmental considerations that constrain/enable the system of interest in ways that can be influential in directing modifications to system design, execution, or development. These expectations represented a major departure from SoSE.

A seventh distinction of CSG is the emphasis on whole system development, where learning takes precedence over 'solution' finding. In one sense, CSG provides a guided 'self-study' of a system of interest to facilitate learning—and corresponding responsive and feasible action—about the system. The exploration identifies 'deep system' issues that are the underlying source of problems in the system. Therefore, CSG was pushed to generate knowledge of the architecture of the CSG functions, the deficiencies (pathologies) in those functions, and the feasibility of addressing the disfunctions. This push of CSG was against the backdrop of establishment of the state of the system and capacity for 'thinking in systems' that is fit to the task. These discoveries are important products and artifacts in CSG endeavors.

Given the need to separate CSG from the evolving SoSE field, at a high level, CSG was targeted to focus on improving the theory and practice of more effectively 'taming' modern complex systems and their problems. CSG draws upon and exists at the intersection of three primary fields, including systems theory, management cybernetics, and system governance. *Systems theory* provides a strong intellectual foundation focused on effective integration and coordination of disparate elements into a coherent whole. This coherent whole must 'obey' the axioms and corresponding propositions of systems theory that govern behavior of systems or suffer the consequences related to deviations. *Management cybernetics* brings an emphasis on communication and control essential to provide for the continuing existence (viability) of a system as it deals with the inevitable internal flux and environmental turbulence endemic to modern complex systems. Consistent with management cybernetics, CSG appreciates and responds to the constant change in the context and environment for a governed system or system of systems. Thus, 'cybernetic steering' emphasizes control necessary to regulate and maintain system stability. This inherently acknowledges the need to monitor the potential impact of near and long-term fluctuations on continuing system viability. Finally, *governance* provides an emphasis on direction, oversight, and accountability for the execution and development of a system. While each of the three fields underpinning CSG have made substantial contributions to the state of human affairs, they have not been brought together in meaningful ways that takes advantage of their intersection to produce a novel alternative to complex system development.

This book does not represent the end state for the development, propagation, and application of CSG. On the contrary, it should be considered a waypoint. A temporary stop to take perspective on what has been accomplished, what is being accomplished, and what lies on the immediate and distant horizon for further development of the CSG field. This book has provided three primary contributions:

1. *Comprehensive Collection of the State of Knowledge for CSG*—There has been a growing body of work produced for CSG. However, the work has been somewhat

fragmented and dispersed in getting to this state. This book is a consolidation of the current state of knowledge in CSG. Therefore, it attempts to bring the body of CSG knowledge together into a coherent framework.

2. *Identification of Gaps in the Knowledge for CSG*—This work serves to collect and organize the state of knowledge for CSG. As a byproduct of this organization, the gaps in knowledge have come to the forefront. This is not a criticism of the work that has been done in CSG. Instead, it identifies CSG field developmental targets that can concentrate efforts.
3. *Definition of the Challenges for the Field and Setting Developmental Priorities*—CSG is no longer held in a limited set of works. Instead, it has amassed a growing set of research, articles, and developmental works. The timing is right for this work to critically survey the CSG knowledge stage, determine the significant challenges, and chart a coherent path forward to the next waypoint.

The purpose of this chapter is to provide an overview of the current state of the CSG field and future directions. This discussion will include achievements, future challenges, and developmental directions to advance the field. The chapter is organized (Fig. 2) to focus on four primary areas. First, a summary of the current state of the CSG Field is conducted. This current state of the field is critiqued with respect to what has been accomplished and present shortcomings. Second, advancement challenges across the spectrum of theoretical/conceptual, methodological, methods,

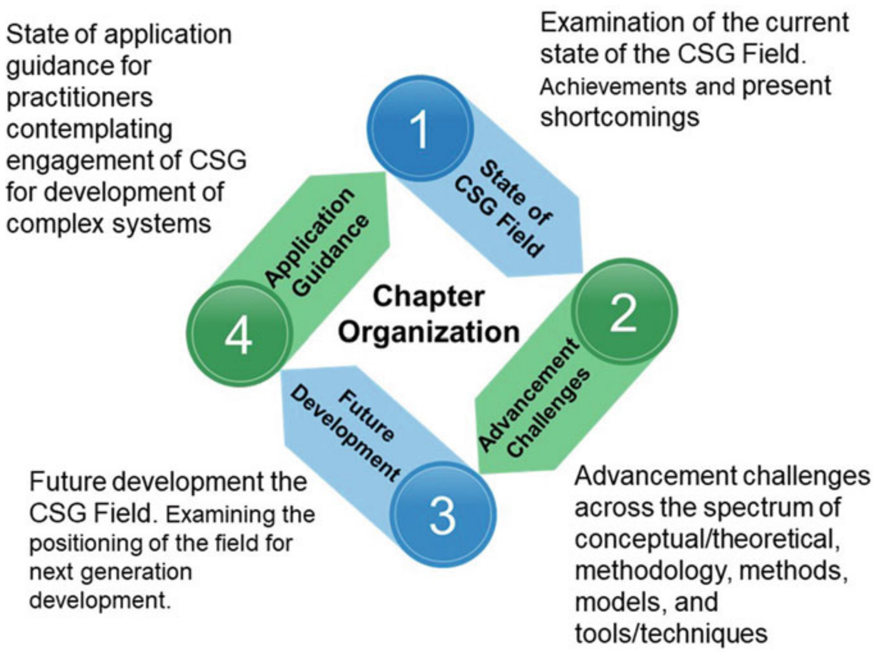

Fig. 2 Chapter organization

tools/techniques, and applications are suggested based on the current state of research and application. Third, the future development of the CSG Field is examined. The positioning of CSG as '*the system-science based engineering of technologies for application to improve design, execution, and development of complex systems*' is explored. This development culminates with a practice and practitioner-based set of guidance to continue advancement of the CSG Field. The guidance attempts to provide an integrated trajectory of the science (theoretical, conceptual, philosophical), engineering (technologies, artifacts, methods), and application (practice tools, techniques, processes) development directions for the field. Fourth, a current state of application guidance for interested practitioners is provided. This guidance is targeted to make the emerging CSG field more accessible to practitioners for the improvement of complex systems. Application emphasizes contributions across individual, organizational, system, infrastructure, and enterprise levels. The chapter concludes with a set of exercises to examine critical issues in the design, execution, and evolution of systems using CSG.

2 The State of the CSG Field

There is a growing body of knowledge related to CSG [47, 51, 52, 56]. CSG is described as the 'Design, execution, and evolution of the [nine] metasystem functions necessary to provide control, communication, coordination, and integration of a complex system.' [48, p. 228]. In this section, we examine the essence of CSG. This essence is found in the nine metasystem functions of CSG and the ten implementing communication channels. Second, an exploration of the essence of CSG as an approach to better deal with complex systems and their problems is conducted. This exploration suggests several points of emphasis that serve as a high-level articulation of the paradigm and central themes of CSG. The section concludes with an assessment of the current state of CSG. The work that has been completed is critically reviewed to set implications for moving the CSG field forward.

2.1 The Essence of CSG—Functions and Communication Channels

The essence of CSG is found in the performance of nine essential governance functions and ten corresponding communication channels. Of all that comprises CSG, the metasystem functions and the communication channels represent the greatest degree of stability. The nine governance functions [52] include the following:

- *Policy and Identity*—Metasystem Five (M5)—focused on overall steering and trajectory for the system. Maintains identity and balance between current and future focus.

- *System Context*—Metasystem Five Star (M5*)—focused on the specific context within which the metasystem is embedded. Context is the set of circumstances, factors, conditions, or patterns that enable or constrain execution of the system.
- *Strategic System Monitoring*—Metasystem Five Prime (M5′)—focused on oversight of the system performance indicators at a strategic level, identifying performance that exceeds or fails to meet established expectations.
- *System Development*—Metasystem Four (M4)—maintains the models of the current and future system, concentrating on the long range development of the system to ensure future viability.
- *Learning and Transformation*—Metasystem Four Star (M4*)—focused on facilitation of learning based on correction of design errors in the metasystem functions and planning for transformation of the metasystem.
- *Environmental Scanning*—Metasystem Four Prime (M4′)—designs, deploys, monitors, and communicates sensing of the environment for trends, patterns, or events with implications for both present and future system viability
- *System Operations*—Metasystem Three (M3)—focused on the day to day execution of the metasystem to ensure that the overall system maintains established performance levels.
- *Operational Performance*—Metasystem Three Star (M3*)—monitors system performance to identify and assess aberrant conditions, exceeded thresholds, or anomalies.
- *Information and Communications*—Metasystem Two (M2)—designs, establishes, and maintains the flow of information and consistent interpretation of exchanges (communication channels) necessary to execute metasystem functions.

The current diagram depicting the CSG functions and communication channels is provided in Fig. 3.

Communication channels represent the second major element of CSG. In substance, the communication channels provide for the flow and interpretation of information in the system, and between the system and the environment (Table 1).

The CSG functions, in concert with the communication channels, produce control, communication, coordination, and integration—in essence the governance responsible for system performance. *Control* establishes constraints necessary to ensure consistent performance and future trajectory. *Communications* provides for flow and processing of information necessary to support consistent decision, action, and interpretation throughout the system. *Coordination* provides for effective interaction to prevent unnecessary instabilities within and external to the system. *Integration* maintains system unity through common purpose, designed accountability, and maintenance of balance between system and constituent interests. Each system is unique in defining 'how' the functions are performed. CSG is concerned with understanding sources of underperforming systems in terms of issues in the design and execution of the nine essential system functions and communication channels. Although addressing underperforming systems is not new, the introduction of CSG offers a new and novel perspective, approach, and system development alternatives. CSG can aid practitioners who must contend with increasing internal flux and external turbulence characteristic of the modern organizational (system) landscape. This landscape

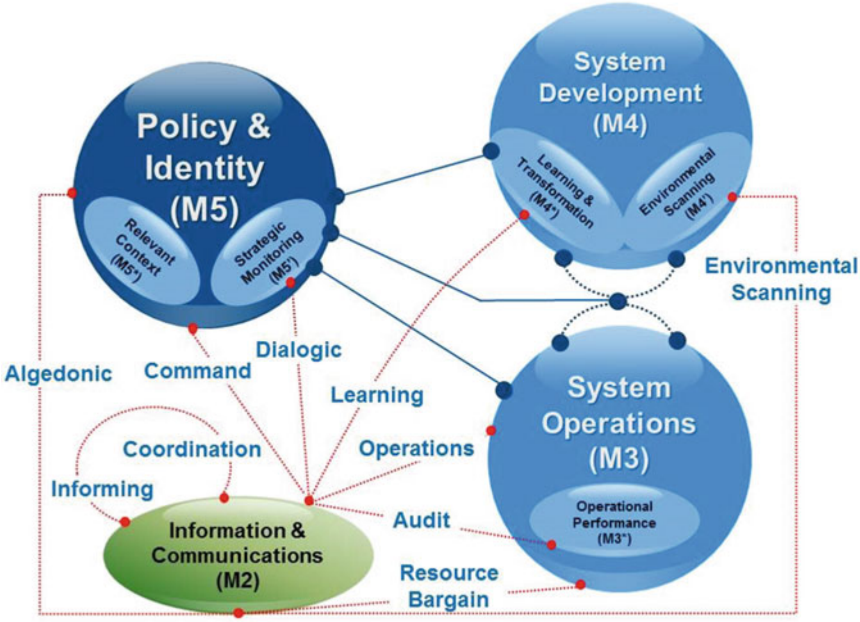

Fig. 3 CSG metasystem functions and communication channels

represents the 'new normal' for systems and their practitioners and shows no signs of subsiding in the near future.

Although the underlying theory, concepts, and execution of CSG are challenging and beyond the scope of this chapter, the essence of CSG is not difficult to grasp. The essence of CSG might be captured in the following statement and elaborated in the four points that follow:

> *Subject to fundamental systems theory propositions, all systems perform essential governance functions. System performance is determined by effectiveness in achievement of governance functions consistent with systems theory propositions. System performance can be enhanced through purposeful development of governance functions.*

There are four fundamental points that help to explain the nature and role of CSG. These include:

- *All systems are subject to the laws of systems*. Just as there are laws governing the nature of matter and energy (e.g., physics law of gravity), so too are our systems subject to laws (*propositions* which include systems theory based laws, principles, and concepts). These system laws are always there, non-negotiable, non-biased, and explain system behavior, structure, and performance.
- *All systems perform essential governance functions that determine system performance.* Nine system governance functions are performed by all systems, regardless of sector, size, or purpose. These functions define 'what' must be achieved for

Table 1 Summary of the CSG communication channels

Communications channel and responsibility	CSG metasystem role
Command (Metasystem 5)	• Provides non-negotiable direction to the metasystem and governed systems • Primarily from the metasystem 5 and disseminated throughout the system
Resource bargain/accountability (Metasystem 3)	• Determines and allocates the resources (manpower, material, money, information, support) to governed systems • Defines performance levels, responsibilities, and accountability for governed systems • Primarily an interface between Metasystem 3 to the governed systems
Operations (Metasystem 3)	• Provides for the routine interface focused on near-term operational focus • Concentrated on direction for system production (products, services, processes, information) consumed external to the system • Primarily an interface between Metasystem 3 and governed systems
Coordination (Metasystem 2)	• Provides for metasystem and governed systems balance and stability • Ensures that information concerning decisions and actions necessary to prevent disturbances are shared within the metasystem and governed systems • Primarily a channel designed and executed by metasystem 2
Audit (Metasystem 3*)	• Provides routine and sporadic feedback concerning operational performance • Investigation and reporting on problematic performance issues within the system • Primarily a Metasystem 3* channel for communicating between Metasystem 3 and governed systems concerning performance issues
Algedonic (Metasystem 5)	• Provides a 'bypass' of all channels when the integrity of the system is threatened • Compels instant alert to crisis or potentially catastrophic situations for the system • Directed to Metasystem 5 from anywhere in the metasystem or governed systems
Environmental Scanning (Metasystem 4')	• Provides design for sensing of the external environment • Identifies environmental patterns, activities, or events with system implications • Provided for access throughout the metasystem as well as governed systems

(continued)

Table 1 (continued)

Communications channel and responsibility	CSG metasystem role
Dialog (Metasystem 5’)	• Provides for examination of system decisions, actions, and interpretations for consistency with system purpose and identity • Directed to Metasystem 5’ from anywhere in the metasystem or governed systems
Learning (Metasystem 4*)	• Provides detection and correction of error within the metasystem as well as governed systems, focused on system design issues as opposed to execution • Directed to Metasystem 4* from anywhere in the metasystem or governed systems
Informing (Metasystem 2)	• Provides for flow and access to routine information in the metasystem or between the metasystem and governed systems • Access provided to entire metasystem and governed systems

governance of a system. Every system invokes a set of unique implementing mechanisms (means of achieving governance functions) that determine ‘how’ governance functions are accomplished. Mechanisms can be formal-informal, tacit-explicit, routine-sporadic, or limited-comprehensive in nature. CSG produces system performance which is a function of previously discussed communication, control, integration, and coordination.

- *Violations of systems theory propositions, in performance of governance functions, carry consequences.* Irrespective of noble intentions, ignorance, or willful disregard, violation of system theory propositions carries real consequences for system performance. In the best case, violations degrade performance. In the worst case violation can escalate to cause catastrophic consequences or even eventual system collapse.
- *System performance can be enhanced through purposeful development of governance functions and communication channels.* When system performance fails to meet expectations, identification of deficiencies in governance functions can offer novel insights into the deeper systemic sources of failure. Performance issues can be traced to governance function issues as well as violations of underlying system propositions (laws, principles, and concepts). Thus, system development can proceed in a more informed and purposeful mode.

At a high level, the paradigm for CSG can be expressed as a straightforward set of relationships and products stemming from CSG (Fig. 4). First, CSG is grounded in the underlying conceptual/theoretical underpinnings found primarily in systems theory and management cybernetics. Second, consistent with this grounding, the set of nine CSG metasystem functions and ten communication channels are performed if a system is to remain viable (continue to exist). Third, the CSG functions and communication channels are performed by the mechanisms (activities, vehicles,

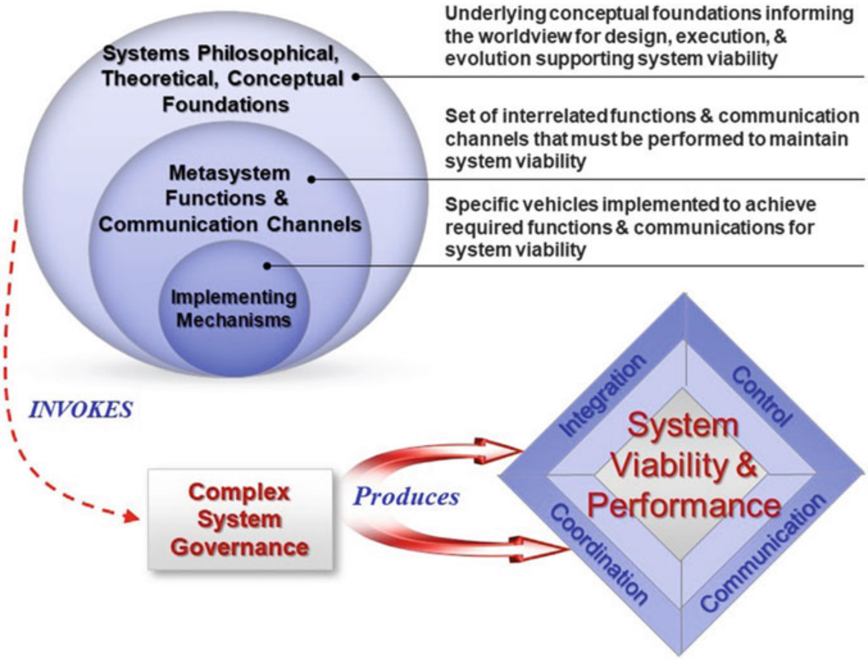

Fig. 4 The CSG paradigm

events, procedures, processes) that serve to enact them—this invokes the performance of CSG. Fourth, the performance of CSG produces system viability, and ultimately, the level of performance through communications, control, integration, and coordination. Thus, complex system performance is grounded in the degree to which CSG is effectively designed, executed, and developed.

2.2 *Points of Emphasis for CSG*

There are several points of emphasis for understanding the basis for CSG in design, execution, and evolution of complex systems. First, *design* accentuates the purposeful and proactive engagement in creation of the governance system. While this seems as though it should be a taken for granted proposition, we suggest that truly purposeful, holistic, and comprehensive design of governing systems represents the exceptional case rather than the norm. Although we might argue the merits of this conclusion, at this point, it suffices to say that based on the current level of system performance of our complex systems, the conclusion seems to be supported. Based on issues propagating all manner and form of our 'manmade' complex systems, the anecdotal evidence suggests that our systems are not sufficiently serving the needs or expectations intended to enhance societal wellbeing. From the CSG perspective, we can see that the integrated and purposeful design for governance is not presently being performed in many of our complex systems. The current state of CSG suggests that there is a significant opportunity to engage 'faulty' complex systems to elevate their performance by purposeful (re)design.

The second element of consideration of CSG revolves around *execution*. Irrespective of purposeful/purposeless design, execution embodies the notion that a design without effective deployment offers little more than good intention. Execution is where a design meets the harsh realities of the 'real world,' which is fraught with complexity and emergent conditions that are sure to test our most thoughtful system designs. For CSG, we suggest that execution is achieved through a multitude of entities and activities. While each of the activities undertaken in support of CSG has merit, a major emphasis of CSG is execution of the design. Lacking execution, CSG is absent an essential element for successful achievement of associated functions.

A third element of CSG, *evolution*, recognizes that systems, as well as their environments, are in constant flux and change over time. Therefore, governance must also be able to flex (evolve) in response to internal and external changes impacting the system over time. Evolution by its very nature suggests that the developmental emphasis is on long-term sustainability, irrespective of the need to operate a system in real time. In effect, governance must be capable of absorbing, processing, and responding to external turbulence and internal system flux. This can ensure the system remains viable (continues to exist). This viability is in both the short-term operational sense that delineates current system existence as well as the long-term evolutionary sense that positions the system for the future. Taking the long view of CSG development, an evolutionary perspective is essential.

CSG is an emerging field focused on helping systems and their practitioners (owners, operators, designers, performers) deal more effectively with increasingly complex systems and their problems. In a nutshell, CSG suggests that we are not inevitably 'doomed' to suffer the ill effects of poorly performing systems. CSG is not offered as a panacea promising to cure all system ills. Instead, CSG offers an alternative path forward for practitioners interested in exploration of new and novel thinking and practice for more effectively dealing with difficult complex systems and problems.

An important emphasis of CSG is that it lies at the intersection of three knowledge streams, Systems Theory (the set of laws that explain the behavior and performance of all systems), Management Cybernetics (the science of effective structuring of systems), and Governance (provision of direction, oversight, and accountability for systems). At the intersection, CSG is focused on the design, execution, and evolution of essential system functions. Proficiency in execution of these functions ultimately determines the level of system performance. The reliance on proven fields enhances the veracity of CSG as an 'intersected' field that draws on a substantial intellectual base.

2.3 *The Current State of CSG*

CSG started in earnest in 2014 [47]. Since that inception, the field has continued to grow in depth and stature. The gains in CSG have spanned the spectrum of theory, methodology, methods, models, tools, and applications. Although still in the embryonic stages, there has been significant progress. Figure 5 provides an overview of the CSG field current state of published works.

CSG has made strides across the six developmental areas necessary to advance the field. A brief accounting of what has been accomplished across each of the areas includes:

- *Conceptual/theoretical*—This represents the most advanced area of CSG development. This is to be expected as the early emphasis of CSG was directed to establishing a solid and well grounded conceptual/theoretical basis. The works in this area have stayed stable as CSG has continued development. This has allowed the other developmental levels to have a reference point that has remained relatively stable. The anchoring of this foundation in systems theory, management cybernetics, and system governance has provided this stability.
- *Methodology*—The area of methodology (the general approach that defines 'what' must be achieved to engage CSG development) has been in place for several years. It has remained relatively intact from the original development. However,

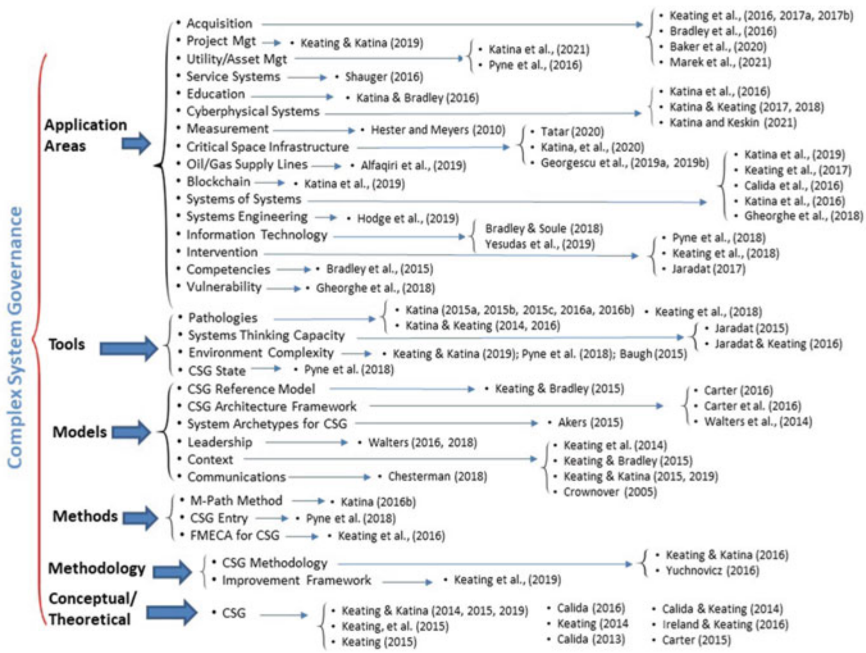

Fig. 5 The current state of the CSG field development

there are two issues with the state of the CSG development methodology. First, the methodology, although conceptually sound, has not seen full engagement for operational deployment. While there have been derivative applications of the 'front end' of the methodology, it has not gravitated to a full engagement. Second, lacking a full engagement, the validation of the CSG development methodology will be lacking.

- *Methods*—In the area of methods to support CSG initiatives there have been several developed. Chief among these are the M-Path method for the discovery and assessment of pathologies in complex systems [36], the CSG Entry method [68] to begin engagement in CSG, and the FMECA for CSG method [57] to discover and assess failure modes in complex systems. While these methods have shown promise, the number of methods developed to support the wide ranging CSG landscape is currently sparse.
- *Models*—The CSG Reference Model remains as the single most prevalent and well developed model for CSG. However, it has not translated into a sufficient set of specific tools or techniques to facilitate deployment of the model in operational settings. Other models have been developed to support specific aspects of CSG, including Communications [18], system archetypes [1], CSG Architecture Framework [17], leadership [71, 73], and Context [19, 55]. While there are models that have been generated to aid in understanding of CSG functions and communications channels, they fall short in number, scope, and operational deployment.
- *Tools*—There are multiple support tools that have been developed for different aspects of CSG. Among the tools are the ST-Cap method for the assessment of systems thinking capacity for individuals [29], Pathologies discovery [32] to identify and process CSG pathologies, Environment Complexity [4] to determine the state of the environment for a complex system, and CSG state [68] to set the current state of the CSG functions and communication channels. While there have been some developments to assist in the performance of CSG, currently there is not sufficient support for practitioners in accomplishment of CSG development.
- *Application Areas*—This is perhaps the least mature of all of the developmental areas for CSG. There have been several documented cases of limited applications of 'parts' of CSG. For example, there have been a variety of application areas (e.g., asset management [39]) identified for utility of CSG. However, actual applications of CSG have been limited, mostly targeted to the initial stages and CSG entry efforts as well as training. Unfortunately, without the demonstration of utility in operational settings, the development and propagation of CSG will be limited.

The current state of CSG is where we might expect for a field in the earliest stages of development. The conceptual foundations are well established and are reaching a point of relative stability. Additionally, there are a host of application areas identified where CSG can contribute. Also, there is the beginning formulation of methods and tools that are being developed to support operational deployment of CSG. However, the application of CSG has seen limited deployment in operational settings. Alleviating this concern will be critical for the continued development of the CSG field.

3 Advancement Challenges for CSG

While the current state of the field is impressive in productivity since 2014, there are several challenges in the continuing evolution of the CSG field. Among these challenges are: (1) early development of CSG was almost exclusively dedicated to first setting the conceptual/theoretical foundations in place—the result is a strong foundation upon which to begin expanding into other aspects, including methods, tools, and techniques, (2) the field is in a position to begin greater emphasis on getting the field directed toward development and deployment of applications for applied settings—this can provide direction for the trajectory of the field and acceleration of advancements through the coupling of theory to practice, and (3) CSG has not been 'stereotyped' to a particular domain/sector for development—while this permits flexibility in the applicability of CSG, it also slows adoption by a lack of an attentive targeted audience. These are the realities of the current state of CSG. While not insurmountable, if CSG is to continue to propagate, it must address these developmental areas.

There are a multitude of contributions that CSG can make to advance the state and practice of complex systems. These contributions can be summarized with respect to the challenges identified in Table 2.

CSG is an emerging field with great potential. Therefore, we must certainly expect challenges, additions, extensions, and insights as the field continues to evolve through research, development, and application. In examination of the challenges for advancing the CSG field, the following development areas have been identified in previous works and remain [15, 46, 47, 55].

- *Holistic field development and application*—continued development of CSG will be well served by research and practice being simultaneously developed. Research must be directed at pursuit of advances across the spectrum of Philosophical (worldviews), Theoretical (explanations concerning phenomena), Methodological (high level guiding frameworks), Axiological (values, value judgments, and beliefs), and Axiomatic (underlying principles). Enhanced practice will be the beneficiary of this holistic development of the field. It is shortsighted to only focus on either research or practice exclusively. Based on the current state of development for CSG, the emphasis on finding opportunities to apply CSG, in part or whole, in operational settings will help to suggest where the field might be enhanced.
- *Focus on Both Practice and Practitioners*—CSG is not an intellectually 'easy' body of knowledge to assimilate. While the theoretical foundations are well grounded, they do not necessarily translate easily to the world of the practitioner. The CSG field should not lose sight of the drive to improve practice and enhance

Table 2 The challenges for CSG to advance complex systems

Challenge	Challenge explanation for complex system governance development
Simultaneous emphasis on design, execution, and evolution	• **Design** is the purposeful and deliberate arrangement of the governance system to achieve desirable system performance and behavior. For complex systems, this suggests making the design explicit and enabling critique against known CSG requirements for effective design. • **Execution** is performance of the system design within the unique system context, subject to emergent conditions stemming from interactions within the system and between the system and its external environment. For complex system, execution provides a path for evaluation as to how effective the execution of the design is in producing performance/behavior desired. • **Evolution** involves the change of the governance system in response to internal and external shifts as well as revised trajectory. For complex system, evolution provides a long view and continual focus on evolving the governing system based on environmental shifts.
Articulate metasystem functions	• Metasystem functions are performed by all viable systems. They serve to provide communication, control, integration, and coordination essential to ensure continuing system performance in the wake of internal flux and environmental turbulence. For complex systems, the purposeful design of metasystem functions can provide performance that fragmented entities and mechanisms will neither be able to achieve nor maintain.
Emphasize design of communication channels	• **Communication** involves the flow, transduction, and processing of information within and external to the system, that provides for consistency in decisions, actions, interpretations, and knowledge creation made with respect to the system. For complex systems, communication is an essential element that should be developed by purposeful design and not left to fortuitous development. Additionally, communications must consider the means and activities beyond the purely technical exchange of information.

(continued)

Table 2 (continued)

Challenge	Challenge explanation for complex system governance development
Design for minimal control (regulatory capacity)	• **Control** is focused on invoking the minimal constraints necessary to ensure desirable levels of performance and maintenance of system trajectory. This is achieved by installing regulatory capacity that permits the system to maintain desired performance in the midst of internally or externally generated perturbations of the system. For complex systems, control suggests that only the constraints necessary to integrate the multiple stakeholders and systems should be invoked. Any excess constraint consumes scarce resources and unnecessarily limits constituent autonomy.
Design for integration of constituent systems	• **Integration** provides for continuous maintenance of system integrity. This requires a dynamic balance between autonomy of constituent entities and the interdependence of those entities to form a coherent whole. This interdependence produces the system identity (uniqueness) that exists beyond the identities of the individual constituents. This permits the system to produce collective behavior/performance beyond that of any of the individual constituent entities.
Design for coordination among constituents	• **Coordination** is focused on providing for interactions (relationships) between constituent entities within the system, and between the system and external entities, such that unnecessary instabilities are avoided. For CSG, coordination becomes a necessary attribute to ensure that the multiple entities, perspectives, and infrastructures are engaged to prevent unnecessary fluctuations and conflict.
Account for context in system development	• **Context** embodies the circumstances, factors, patterns, conditions, or trends within which a system is embedded. It acts to constrain or enable the system. The inclusion and accounting for context in complex systems is critical to improve system performance. All complex systems are embedded in a unique context that enables/constrains a system. Removing the 'system' elements from the context to simplify for assessment purposes creates a false separation between the 'system' and its context, as they are integral to one another.

(continued)

Table 2 (continued)

Challenge	Challenge explanation for complex system governance development
Account for environment constraining or enabling the system	• **Environment:** The aggregate of all surroundings and conditions within which a system operates. It influences, and is influenced by, a system. The environment is a source of variability and constraint for a complex system. The accounting for the environment is critical to system development. The environment is the source of input (resources) for a system and also the place where the value of the system (products, services, information) is consumed.

the capabilities of practitioners to deal more effectively with complex systems and their problems. CSG field development should include the need for methods, tools, and techniques necessary to support applications. These artifacts of CSG must also appreciate that the application of them may be by practitioners not necessarily well steeped in the theoretically underpinnings of CSG. Thus, the development pathways may be adjusted to compensate for limited practitioner knowledge. However, what cannot be lost on CSG challenges for development is the need to develop practitioners, as well as their complex systems, to effectively engage methods, tools, and techniques from a 'systems worldview'. This represents a challenge to CSG and should also be a primary development concern.

- *Emphasis on sustainable field development*—development of the CSG field should focus on long term evolutionary development. This presents a difficult challenge, given the short term views that are limited in compatibility with the 'long view' required by CSG. However, the CSG field should not be subjected to a 'faddish' development, making claims and promises that are unrealistic and not likely to be achieved. Instead, care must be taken such that the field does not create expectations that are unrealistic for the current stage of development. Unrealistic expectations at best will cause disappointment amid initial fanfare. At worst, unrealistic expectations might do harm to the reputation of CSG as an approach to improve complex systems. The result of unnecessary pressures on CSG deployment will either result in the field being minimized at best or suffering an early demise at worst.
- *Maintenance of theoretical grounding for field sustainability*—there is a propensity for the 'quick hit', large value proposition for improving practices in operational settings. While this 'instant' gratification perspective is pervasive, care must be taken to make sure that the continuing development of the CSG field is not ignored. If CSG is to maintain coherence in continued development, it will be necessary to maintain the grounding of the field in a strong conceptual/theoretical base. For CSG this involves field evolution around systems theory, governance, and management cybernetics. In addition, there should be no hesitation to pursue further elaboration of the theoretical basis of CSG as a work in progress.

CSG development, as with any emerging field, will not be without challenges and issues. However, purposeful development of the field will certainly accelerate the path of development. While the CSG field is certainly not portrayed as a panacea that can cure all of the ills of modern complex systems or produce renaissance practitioners, it offers a different systems-based approach to improve complex systems. Additionally, CSG offers practitioners an additional set of capabilities to more effectively enhance practices related to complex systems.

Many of the greatest challenges facing the CSG field development have to do with the challenges to deploy CSG, CSG methods, and CSG tools. To succinctly articulate these deployment challenges, Table 3 provides the challenge area and explanation of the challenge.

There are significant challenges for deployment of CSG. However, there are deployment challenges for any systems-based methodology. The set of deployment challenges must be factored into efforts to utilize CSG in operational settings.

Vignette–This is hard stuff and a bit threatening

This example captures the difficulties in application of CSG. In this instance, an organization (system) was interested in exploring the possibilities that CSG might hold for improvement in their operations. Through an introduction, briefings on the essence of CSG, and application of several exploratory instruments, the exploration continued. The initial 'dive' into CSG suggested several areas in the system where pathologies (systemic deficiencies) existed, and the environment was demanding more than the system could accommodate. The interest started to quickly wane with the realization that there were no quick fixes. The exploration discovered that the sources of issues stemmed from the current design of the system and the overreliance on execution to compensate for a design that had deficiencies. Then the stark realizations set in that: (1) further understanding and development of actions to address the system design issues were nontrivial, (2) significant investment of their time/energy would be necessary to operate on the system instead of continue to 'band aid' the system to maintain viability, at whatever low levels initially sparked the interest in CSG, and (3) the option to 'do nothing' was much less threatening to the 'status quo' than starting to turn over rocks, underneath which might not be pleasant findings. In short, CSG presented an interesting diversion, but the continued and escalating search for deep system improvements were beyond the capacity of the system to engage.

4 Future Development Directions

Thus far, we have examined the current state and challenges for the CSG field. In this section, we examine specific developmental directions and potential to further develop CSG. There has been significant literature that has developed the foundations of CSG as an emerging field [52]. In this section, we examine four aspects for future development of CSG. First, the three interrelated developmental areas of science, engineering, and application are examined for CSG. These three areas are examined in relationship to their joint influence on practice. Second, seven interrelated developmental thrusts are suggested for CSG. Progression of the CSG field is dependent on the joint and balanced development across the thrust areas. Third, current challenges for accelerating the development of CSG are examined. These

Table 3 Challenges for deployment of CSG

Challenges	Explanation
Sufficient level of systems thinking to engage CSG	Engagement in CSG requires significant capacity for systems thinking. Absent this requisite capacity, it is unlikely that CSG will have the anticipate results. Instead, it is likely that CSG efforts will fall short of expectations. Systems thinking must be assessed, and if short of that necessary for engaging development activities, should have methods to increase systems thinking capacity integrated into the development application
Limited patience for the long view and immersive self-study	There is limited patience for seeing results occur over a long duration. This short-term fixation works against the deployment of CSG initiatives. CSG, by design, is focused on the long-term development of systems. Lacking patience for the long view of system development is detrimental to the prospects for CSG development. CSG requires that a system be studied by those with the responsibility/accountability for governance functions and communications channels. Lacking engagement for self-study casts doubt on effectively engaging CSG
Preference for tools and applications over deep systems development	Given a propensity for superficial thinking and action in response to system development, emphasis on tools and applications are preferred. Unfortunately, this preference is not well served by CSG. Tools and applications certainly have a place in CSG. However, the deeper levels of methodology (understanding what must be done) and the grounding in systems thinking (taking a holistic/systems theory viewpoint) requires going deeper than the superficial application of tools/techniques to holistically address truly complex system issues
Overcoming the ‘in addition to’ syndrome	CSG is not something that is done in addition to what is already being performed by practitioners in a complex system. If the system is viable (continuing to exist), then the CSG functions and communication channels are already being performed. They may not call the functions and communications channels by their CSG nomenclature, but they are being performed. Therefore, CSG is not something that is ‘in addition to’ what is being done. This places CSG in a privileged position of not being totally new and novel to what is already being performed. However, the difficulty of communicating this point is challenging

(continued)

Table 3 (continued)

Challenges	Explanation
Appreciation that systemic intervention by CSG has many failure modes	There is no guarantee that a CSG systemic intervention will be successful. There are too many variabilities in the deployment of CSG to arrogantly claim that it will be successful. On the contrary, tempering expectations is essential, since the precise results from a CSG systemic intervention cannot be know or predicted in advance. Instead, the results will emerge in unpredictable ways, irrespective of the noble intentions of the intervention
Perceived threat to the status quo	CSG ultimately shifts power to resolve uncertainty from individuals to the system of interest as a whole. Additionally, identification of 'deficiencies' in the design or execution of CSG functions can 'wrongly' be assumed to indicate a failure of complex system leadership. Unfortunately, the perceived threat to the 'status quo' system operation is likely to challenge the continuing and deepening exploration into systemic deficiencies

challenges must be met if CSG is to achieve the promising potential for impact of the field. Fourth, a set of guidance considerations for practitioners contemplating engagement of CSG is provided.

4.1 CSG Development Across Science, Engineering, and Application

CSG has not been disseminated or projected to the much wider community of practitioners across multiple sectors. CSG has the potential to significantly improve capabilities for practitioners (owners, operators, performers, designers) responsible for the design, execution and development of complex systems. We suggest that the utility of CSG proceeds along three interrelated streams of development, including *science, engineering, and application, all* targeted to improvement of practice. To look at these three aspects of the development of a field as independent and mutually exclusive of one another is false and somewhat naive. The CSG field faces a major challenge to pursue parallel integrated paths of development for the science, engineering, and application of CSG. The easy, and more traditional research approach is to separate the development of underlying science from corresponding engineering technologies and eventual applications. However, there is much to be gained by permitting the triad to constrain as well as enable one another for accelerated CSG field development. The research path that emerges through the integration of science, engineering, and application may be very different than if joint development had not been considered. It is certainly arguable that the CSG field currently pursues research that engages a close correlation between science, engineering, and application domains. There is much to gained by pursuit of CSG field development that explicitly couples science, engineering, and applications by design from an integrated systems perspective (Fig. 6).

For purposes of this discussion, we take *science* broadly as the search for knowledge to develop testable theory and laws related to a field. The tenets of good science include disciplined inquiry that can withstand the scrutiny of a particular field. The results of science must be theories and laws that can be tested to determine their continued power to provide confirmation or to be refuted. For CSG, this suggests that the discovery of new tenets of science supporting CSG may be found at the intersection of CSG's foundations in systems theory, management cybernetics, and system governance. In fact, systems theory is the doctrine that instantiates system science foundations. It would be easy to dismiss development of the science thrust for CSG as nonessential or a frivolous waste of scarce resources. However, engineering of technologies and their supporting applications, without grounding in the underlying science, misses an important stable base. While engineered technologies and applications can change rapidly, the underlying theoretical/scientific basis for a field provides long-term stability. The importance of this stable science-based foundation for the emerging CSG field cannot be overstated. This is particularly the case given

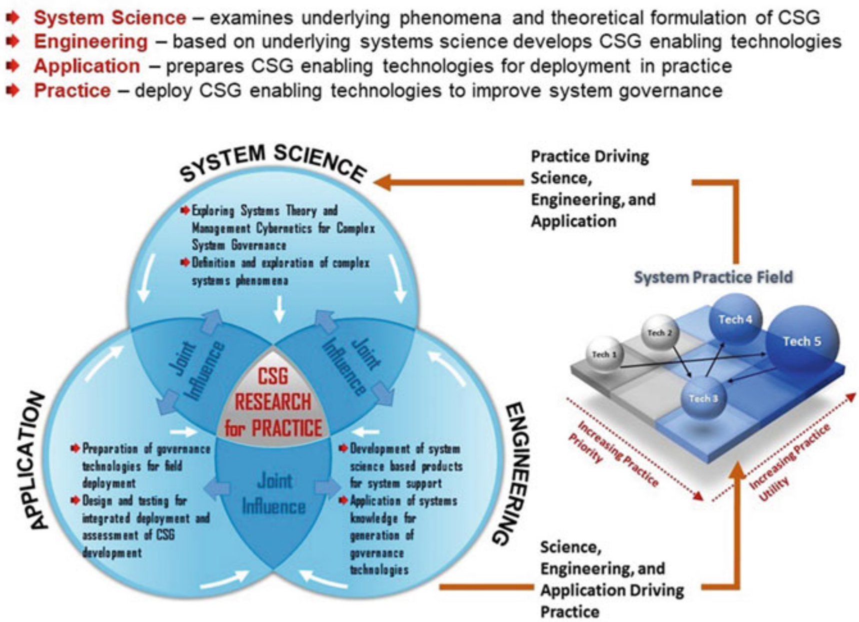

Fig. 6 CSG field development integrating science, engineering, and application for practice

the increasingly turbulent conditions faced by professionals and programs that seek to address complex systems and their problems across a multitude of sectors.

Engineering engages science to develop innovations that solve problems and increase the capabilities of practitioners to function more effectively. Thus, engineering becomes a bridge between science and application. This occurs through the development of science-based technologies for application support. Finally, applications involve putting science-based engineering technologies into action to support human purposes. Ultimately, the applications deployed by practitioners provide utility for science-based technologies. We believe that CSG research must be engaged and integrated across each of the three levels (science, engineering, applications) if it is to provide sustainable improvement of practices for the CSG field. Additionally, there must be eventual deployment in operational settings. The interrelated advancement across these three developmental thrusts for CSG will: (1) accelerate development of each of the other thrusts, (2) provide a grounding to better inform each of the thrust areas such that different development directions and insights might be possible, and (3) draw the worlds of science, engineering, application, and practice closer together to provide a more balanced development of the CSG field. Ultimately, the future development of CSG must rely on the *system-science based development of engineering technologies for application to improve practice.*

4.2 The Seven Developmental Thrusts for CSG

The future development of CSG must achieve balance across seven developmental thrusts. Following earlier work by Keating [62] related to field development (Fig. 7). These seven levels are interrelated and provide guidance to maintain a balance, ensuring a holistic treatment of the field.

The seven developmental thrusts, and associated questions that should provide a focus for CSG field research and development include:

- ***Philosophy***—research directed at developing a theoretically consistent articulation of the paradigm(s) for Complex System Governance. The emerging system of values and beliefs providing grounding for theoretical development is the primary contribution of this area.

  Questions for consideration: *(a) What are the epistemic foundations for CSG?, (b) What are the ontological predispositions for CSG?, (c) What are the existing and emerging paradigms that can serve to inform CSG?, and (d) How can philosophical disposition be identified, represented, and evolved for practitioners and entities engaging in CSG?, and (e) What are the implications for philosophy application concerning design, execution, and evolution of complex systems and CSG?*

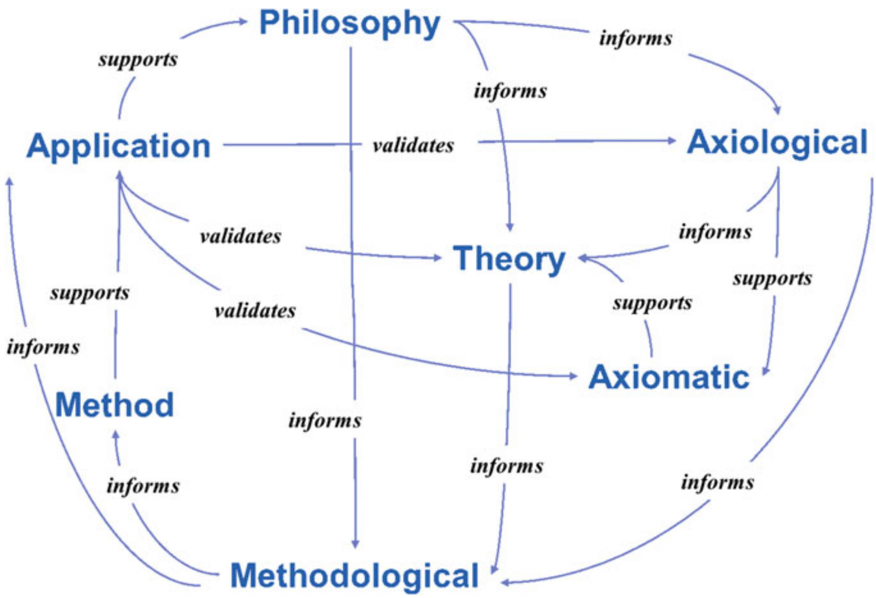

Fig. 7 Interrelated development thrusts for balanced development of the CSG field

- ***Theoretical***—research focused on explaining phenomena related to complex system governance and development of explanatory models and testable conceptual frameworks. The range of theoretical developments advances understanding of the field.

  Questions for consideration: *(a) What explanatory frameworks or models can be created to support CSG?, (b) What informing theoretical models are instructive for CSG?, (c) What are the phenomena in question with respect to CSG design, execution, and evolution?, and (d) How can prediction of CSG outcomes be supported and tested?*
- ***Axiological***—research that establishes the underlying value, value judgment frameworks, and belief propositions that are fundamental to understanding the variety of perspectives for Complex System Governance.

  Questions for consideration: *(a) What are the values informing different variants of CSG?, (b) How can axiological dispositions be measured and modeled for CSG and possibly changed?, and (c) What effect do values/value judgments have on design, execution, and evolution of CSG?*
- ***Methodological***—research undertaken to develop the theoretically informed frameworks that provide high level guidance for design, analysis, deployment, execution, and evolution of complex governance systems.

  Questions for Consideration: *(a) What frameworks can be constructed, or derived, to guide CSG design, analysis, diagnostics, and transformation?, (b) How can methodologies for CSG be tested and validated?, and (c) What technologies can be developed to support and execute CSG methodologies?*

- ***Axiomatic***—investigation into the emerging principles, concepts, and laws that define the field and constitute the "taken for granted" knowledge upon which the field rests. This also includes integration of knowledge from other informing and related fields/disciplines.

  Questions for consideration: *(a) What are the emerging areas where principles must be developed to support CSG? and (b) What existing principles can be incorporated or adapted to inform CSG, beyond those currently informing the CSG field?*
- ***Method***—research focused on development of the specific models, technologies, standards, processes, and tools for Complex System Governance. This is, in effect, the development of the toolsets and capabilities to enable practitioners to perform in the Complex System Governance domain.

  Questions for Consideration: *(a) What technologies, tools, processes, procedures, tools, or techniques can be developed to support performance of CSG? and (b) How can appropriate methods be selected for performing CSG?*
- ***Application***—advancement of the practice of Complex System Governance through the deployment of science based methodologies, technologies, and methods.

  Questions for Consideration: *(a) What standards/guidance can be developed to enhance the practice of CSG?, (b) What are best practices for CSG across different systems?, and (c) How can CSG be effectively deployed and measured in an operational setting?*

CSG is not a panacea for improving the prospects for more effective development of complex systems. However, CSG does offer a strong systems science grounded, engineering-focused, and application-oriented approach. This approach targets improving practices related to enhanced governance of complex systems in a more rigorous and purposeful manner. The development of CSG is dependent upon the degree to which there is a balance among and between the different field development levels suggested above.

4.3 Current Challenges and Research Directions to Advance the CSG Field

Based on the current state and trajectory of the CSG field, there are six challenges for research and development to accelerate advancement of the field. While these areas are not suggested as the 'complete' set of challenges and directions, they are representative of areas that need attention if CSG is to progress toward achievement of its full potential.

1. *Vigilant pursuit of practice improvement as the primary driver*—ultimately, all that is done in pursuit of the CSG field has the baseline purpose of improving

complex system performance. This must be achieved through advances in practice and enabling capabilities for practitioners. The farther away from this fundamental understanding CSG research and development gets, the less likely the CSG field will fulfill its potential.

2. *Emphasis on development of tools, methods, techniques, processes, and technologies to enable practice*—to improve practices related to CSG, practitioners must be armed with appropriate artifacts that will enable success in CSG applications. Absent these artifacts, it is unlikely that CSG will be capable of efficient/effective deployment in operational settings.
3. *Focus on making CSG approachable for application*—CSG is a difficult topic to grasp let alone master. In some sense it becomes unapproachable by practitioners who might benefit from CSG application but lack the time for protracted study of the subject. Thus, a major developmental thrust for the CSG field must revolve around making the field accessible to 'everyday' practitioners. If CSG remains unapproachable to all but a few, the objective of preparing practitioners to deploy CSG will be forfeit.
4. *CSG deployment must be capable of engaging a range of applications*—CSG must avoid being cast as a binary (all or nothing) application. Instead, CSG must be identified for application across a spectrum of potential deployment opportunities. In this sense, smaller scope applications can be included in the CSG application opportunities.
5. *Finding tenable balance in the Risk-Reward-Value tradeoff for CSG deployment*—There can be considerable perceived risk inherent in engagement of a CSG effort. Care must be taken to allay unsubstantiated fears of excessive risk from engaging CSG development. Also, the value accrued and reward for engaging CSG should be made explicit and palatable. Thus, the burden (perceived risk) of engagement in CSG can be lessened.
6. *Making CSG measurable such that improvement can be captured and monitored over time*—CSG can be resource intensive. The current state and transition possibilities enabled by CSG should be made explicit. Additionally, there should be a corresponding set of 'metrics' that can serve to measure and monitor progression in system performance being accrued from CSG development efforts.

Although this set is not presented as absolute or complete, it does suggest a necessary set of considerations related to how CSG can be better designed for engagement in complex systems.

4.4 Practitioner Guidance for Deployment of CSG

Application of CSG is a difficult endeavor to say the least. However, to gain a better grasp of preparing for successful engagement in CSG, there are several areas for consideration. These areas, although not a complete set, help prepare practitioners to embrace the prospects for successful CSG endeavors. This set of guidance for application of CSG includes:

1. *CSG development must involve the individuals who own the system, are accountable for system performance, and responsible to ensure that the system continues to develop such that viability is maintained.* CSG development pursuit without engagement of these individuals is unlikely to achieve anticipated results. There is no shortcut for system practitioners—CSG responsibility cannot be relegated or delegated.
2. *Individual capacity, organizational competence, and infrastructure compatibility to engage in systemic thinking/action will determine the degree to which system governance can enhance system performance.* Without a commensurate effort to understand the impacts, and necessity to include their development, these three areas (individual capacity, organizational competence, and infrastructure compatibility) can severely limit CSG developmental achievements.
3. *The focus on development for CSG efforts can include practitioner, support infrastructure, system, organization, or context.* It is shortsighted to only view CSG development as targeted to the system of interest. There are many potential benefactors and beneficiaries for a CSG effort. The more expansive and holistic the view of CSG development is the more likely deeper developmental impacts can be achieved.
4. *Feasible actions to improve the governance system are a function of the degree of engagement, resources, will, and the existing state of 'governance' for the system of interest.* Realization of 'full potential' for CSG development requires alignment of all of these elements. Outcome-expectation desires that are incongruent with investments of time, energy, commitment, and resources are likely to produce disappointing results.
5. *Greater understanding of a system of interest targeted for development accrues through the process of model construction.* Modeling efforts can provide insights into the structural relationships, context, and systemic deficiencies that exist for a system of interest. These insights can accrue regardless of whether or not specific actions to address issues are initiated. The models can be constructed without system modification and can range in degree of depth and sophistication. Therefore, alternative decisions, actions, and interpretations can be selectively engaged based on consideration of insights and understanding generated through system of interest modeling efforts.
6. *CSG application provides insights for alternative decisions.* CSG provides the 'big picture' view of the governance landscape. This includes identification of highest leverage strategic impact areas and their interrelationship to the larger CSG performance gaps. Thus, decisions for resource allocation can be better targeted. This allows steering away from activities that are simply 'intriguing' without demonstrating the highest substantial benefit to the larger

'systemic' governance concerns (e.g., pathologies). In light of CSG development priorities, low contribution efforts can be eliminated, or resources shifted appropriately.

7. *The design for comprehensive governance development is fallible and must be continually adjusted.* It is naïve to engage in CSG development assuming that precise outcomes can be known in advance. Instead, care must be taken to understand that the design for CSG development cannot be static. CSG development must adjust in response to changes in the system itself, the external environment, and the context within which CSG is embedded. The rate of change for CSG development design must minimally keep pace with the rate of change in the system, external environment, and context.
8. *The nature of CSG development is evolutionary rather than revolutionary.* Therefore, the implementation of CSG development requires 'the long view' and patience. CSG resists the 'quick fix' mentality prevalent in many development initiatives. Expectations for CSG development must be appreciative of the current state of governance effectiveness, which did not recently appear, but rather evolved over time. This CSG state will dictate what level of system improvement might be feasibly engaged over the near and long term.
9. *In essence, CSG development is a protracted 'self-study' of the system of interest, enacted through a new set of lenses, corresponding language, methods, and tools.* New thinking requires new language, which can produce alternative decision, action, and interpretation in route to pursuit of different outcomes (system performance levels). The willingness to engage in protracted self-study is essential for realization of the benefits of CSG development. There is no shortcut to the reflective self-study required to fully realize the potential of CSG to improve performance in complex systems and address their problems.
10. *Engaging governance development is not a trivial endeavor.* It is hard work, requiring significant investment of resources, patience to take the 'long view', and sacrifice of instant gratification for sustainable longer term performance improvement. Superficial CSG efforts are not likely to produce desirable or sustainable results, and in fact may make matters worse.

The essence of the emerging CSG field is focused on improving the ability of practitioners to more effectively deal with complex systems and their problems. CSG has the potential to significantly improve capabilities for practitioners (owners, operators, performers, designers) of complex systems. The guidance provided above offers a set of considerations for practitioners contemplating engagement of CSG.

5 Summary

This chapter has provided an overview of the genesis, current state, and future directions for the emerging CSG field. CSG was presented as a necessary evolution of the SoSE field. The CSG evolution was cast as a departure to complement traditional forms of SoSE, which were focused primarily on development of technology integration for large complex systems. The necessity to include the range of human, social, organizational, managerial, political, and policy aspects of complex systems is a major emphasis for CSG. In essence, this emphasis entails the inclusion of the 'soft' aspects of complex systems in addition to the 'hard' aspects. What was taken forward from the SoSE traditional formulation were the importance of technology in wider CSG applications and the rigorous formulation, albeit more holistic in orientation, driven from the engineering perspective.

The evolution of CSG emerged as the 'Design, execution, and evolution of the [nine] metasystem functions necessary to provide control, communication, coordination, and integration of a complex system.' [48, p. 228], which was a clear delineation of CSG from SoSE as well as other systems-based approaches for complex systems. The inclusion of *systems theory* (axioms and propositions that explain the behavior, structure, and performance of complex systems and which all complex systems are subject to), *management cybernetics* (communication and control as the science of effective structural organization), and *governance* (high-level steering of a system through direction, oversight, and accountability) were introduced as the supporting theoretical and conceptual foundations for CSG.

The essence of the CSG field stemming from the performance of nine essential governance functions and corresponding communication channels was explored. These functions and communication channels were presented as essential for a system to maintain viability, are present in any viable system, and are the source for aberrant behavior or performance (pathologies) in complex systems. The essence of CSG was established as, '*Subject to fundamental systems theory propositions, all systems perform essential governance functions. System performance is determined by effectiveness in achievement of governance functions consistent with system theory propositions. System performance can be enhanced through purposeful development of governance functions.*' This articulation capsules CSG. The CSG paradigm was introduced as the overarching depiction of CSG, linking the central aspects of CSG to production of system performance.

The current state of CSG was introduced. The CSG field was recognized, albeit emerging as a new and novel field, as having made significant and balanced progress since its formal inception in 2014. Advances across the conceptual/theoretical, methodology, methods, models, tools, and application areas were examined. While the state of CSG has been evolving rapidly, there is still much to be done as the maturation of the field continues. The advancement challenges for CSG were examined to focus complementary efforts to the contributions made thus far in development. Several development areas were suggested, including: (1) the need for holistic field development and continued emphasis on application and practices in operational settings, (2) the need to focus on the practice of CSG and emphasizing the need to enable CSG to be 'approachable' for practitioners and balancing the Risk-Reward-Value tradeoff, (3) continued emphasis on balanced and sustainable field development, (4) maintaining and evolving the theoretical grounding of CSG to ensure sustainability of the field, and (5) making CSG measurable to demonstrate system improvement. These challenges were extended by addressing the specific challenges related to deployment of CSG for operational settings. The particular ‘resistance’ areas for which CSG deployment must be evolved were also identified.

Future development directions for CSG were established. These development directions were captured as the balancing across science, engineering, and application to influence higher states of practice for CSG. Ultimately, the thrust of development for CSG is the improvement of practice for complex systems and enabling practitioners to more effectively engage complex systems and their problems. Seven development thrusts were suggested to mature the CSG field, including philosophy, axiological, theoretical, axiomatic, axiomatic, method, and application levels. The interrelated and balanced development in these seven areas were suggested. Development was also examined with the presentation of current challenges and research directions to advance the CSG field. The chapter concluded with a set of practitioner guidance to suggest the limitations and considerations that should be considered before engagement in CSG endeavors.

The emerging field of CSG is not presented as the ‘magic elixir’ or solution to all that is problematic in complex systems. CSG is not a trivial treatment that can be prescriptively applied to deficient complex systems and perform some miracles that heal the system deficiencies. Instead, CSG is an emerging field that offers a theoretically grounded, nontrivial application approach, action orientation, improvement focused, and holistic treatment for complex systems and their problems. Ultimately, CSG is about enhancing practice and enabling practitioners to engage complex systems and their problems more effectively.

Exercises

1. Discuss the evolution of CSG as a departure from SoSE formulations and why this departure was necessary.
2. Identify the three most significant contributions that CSG can make to improve complex system performance.
3. Identify the impediments to deployment of CSG in operational settings. Discuss what might be done to enhance the approachability of CSG for deployment to enhance practice.
4. Identify the three primary challenges for advancement of the CSG field and implications for research directions that should be engaged to address these challenges.

References

1. Akers W, Keating CB, Gheorghe A, Sousa-Poza A (2015) The nature and behaviour of complex system archetypes. Int J Syst Syst Eng 6(4):302–326
2. Alfaqiri A, Hossain NUI, Jaradat R, Abutabenjeh S, Keating CB, Khasawneh MT, Pinto CA (2019) A systemic approach for disruption risk assessment in oil and gas supply chains. Int J Crit Infrastruct 15(3):230–259

3. Baker W, Castelle K, Bradley J, Marino L (2020) Design for sustainment: governance engineering in major acquisition programs. In: Proceedings of the seventeenth annual acquisition research symposium. Monterey, California, pp 1-18
4. Baugh D (2015) Environmental scanning implications in the governance of complex systems. Int J Syst Syst Eng 6(1–2):127–143
5. Beer S (1979) The heart of enterprise. Wiley, New York
6. Beer S (1985) Diagnosing the system for organizations. Wiley, Hoboken, NJ
7. Beer S (1981) Brain of the firm: the managerial cybernetics of organization. Wiley, New York
8. Bradley JM, Joiner KF, Efatmaneshnik M, Keating CB (2017) Evaluating Australia's most complex system-of-systems, the future submarine: a case for using new complex systems governance. In: INCOSE international symposium, vol 27, no 1, pp 187–199
9. Bradley JM, Soule RT (2018) Information technology governance through the complex system governance lens. In: INCOSE international symposium, vol 28, no 1, pp 1237–1249
10. Bradley JM, Unal R, Pinto CA, Cavin ES (2015) Competencies for governance of complex systems of systems. Int J Syst Syst Eng 6(1–2):71–89
11. Bradley J, Katina P, Keating C (2016) Complex system governance for acquisition. Leading Change, LLC Augusta United States
12. Calida BY (2013) System governance analysis of complex systems. Doctoral Dissertation. Old Dominion University
13. Calida BY (2016) Complex system governance: moving diverse theory to practice. Int J Syst Syst Eng 7(1–3):22–42
14. Calida BY, Jaradat RM, Abutabenjeh S, Keating CB (2016) Governance in systems of systems: a systems-based model. Int J Syst Syst Eng 7(4):235–257
15. Calida BY, Keating CB (2014) System governance: emergence of practical perspectives across the disciplines. In: Gheorghe AV, Masera M, Katina PF (eds) Infranomics: sustainability, engineering design, and governance. Springer, New York, pp 269–296
16. Carter B (2015) A metasystem perspective and implications for governance. Int J Syst Syst Eng 6(1–2):90–100
17. Carter B, Moorthy S, Walters D (2016) Enterprise architecture view of complex system governance. Int J Syst Syst Eng 7(1–3):95–108
18. Chesterman CW Jr (2018) Contextual framework of communications functions supporting complex system governance. Old Dominion University
19. Crownover WM (2005) Complex system contextual framework (CSCF): a grounded-theory construction for the articulation of system context in addressing complex systems problems. Old Dominion University
20. Georgescu A, Gheorghe AV, Piso MI, Katina PF (2019) CSI—a complex system governance approach. In: Critical space infrastructures. Springer, Cham, pp 281–320
21. Georgescu A, Gheorghe AV, Piso MI, Katina PF (2019) CSG: towards CSI research. In: Critical space infrastructures. Springer, Cham, pp 321–343
22. Gheorghe AV, Vamanu DV, Katina PF, Pulfer R (2018) Governance vulnerability facets. In: Critical infrastructures, key resources, key assets. Springer, Cham, pp 39–79
23. Gheorghe AV, Vamanu DV, Katina PF, Pulfer R (2018) System of systems governance. In: Critical infrastructures, key resources, key assets. Springer, Cham, pp 93–130
24. Hester PT, Meyers TJ (2010) The role of measurement in complex system governance
25. Hodge RJ, Craig S, Bradley JM, Keating CB (2019) Systems engineering and complex systems governance–lessons for better integration. In: INCOSE international symposium, vol 29, no 1, pp 421–433
26. Ireland V, Keating C (2016) Introduction to special issue on complex system governance. Int J Syst Syst Eng 7(1/2), 3
27. Jackson MC (2019) Critical systems thinking and the management of complexity. Wiley
28. Jaradat RM (2015) Complex system governance requires systems thinking-how to find systems thinkers. Int J Syst Syst Eng 6(1–2):53–70
29. Jaradat RM, Keating CB (2016) Systems thinking capacity: implications and challenges for complex system governance development. Int J Syst Syst Eng 7(1–3):75–94

30. Jaradat RM (2017) Systemic intervention for complex system governance development. In: Proceedings of the international annual conference of the American society for engineering management. American Society for Engineering Management (ASEM), pp 1–10
31. Katina P, Keating C (2016) Metasystem pathologies: towards discovering of impediments to system performance. In: Proceedings of the 2016 industrial and systems engineering research conference, pp 1–6
32. Katina PF (2015) Systems theory-based construct for identifying metasystem pathologies for complex system governance. Old Dominion University
33. Katina PF (2015) Emerging systems theory–based pathologies for governance of complex systems. Int J Syst Syst Eng 6(1–2):144–159
34. Katina PF (2016) Systems theory as a foundation for discovery of pathologies for complex system problem formulation. In: Applications of systems thinking and soft operations research in managing complexity. Springer, Cham, pp 227–267
35. Katina PF, Keating CB, Sisti JA, Gheorghe AV (2019) Blockchain governance. Int J Crit Infrastruct 15(2):121–135
36. Katina PF (2016) Metasystem pathologies (M-Path) method: phases and procedures. J Manag Dev
37. Katina PF, Keating CB (2014) Metasystem pathologies: towards a systems-based construct for complex system deficiencies. In: Proceedings of the international annual conference of the American society for engineering management. American Society for Engineering Management (ASEM), p 1
38. Katina PF, Keating CB (2018) Cyber-physical systems governance: a framework for (meta) cybersecurity design. In: Security by design. Springer, Cham, pp 137–169
39. Katina PF, Keskin OF (2021) Complex system governance as a foundation for enhancing the cybersecurity of cyber-physical systems. Int J Cyber Warfare Terror (IJCWT) 11(3):1–14
40. Katina PF, Calida BY, Bobo JA (2020) Complex system governance: advancing prospects for critical space infrastructure applications. Space Infrastruct Risk Resil Gov 57:29
41. Katina PF, Keating CB, Bradley JM (2016) The role of 'Metasystem' in engineering a system of systems. In: Proceedings of the 2016 industrial and systems engineering research conference, pp 1–6
42. Katina PF, Keating CB, Gheorghe AV (2016) Cyber-physical systems: complex system governance as an integrating construct. In: Proceedings of the 2016 industrial and systems engineering research conference. Anaheim, CA: IISE
43. Katina PF, Keating CB, Bobo JA, Toland TS (2019) A governance perspective for system-of-systems. Systems 7(4), 54
44. Katina P, Bradley JM (2016) Towards a systems theory-based curriculum for complex systems governance. In: 2016 ASEE annual conference and exposition
45. Katina PF (2015) Systems theory-based construct for identifying metasystem pathologies for complex system governance. Doctoral dissertation, Doctoral Thesis, Old Dominion University, Norfolk, VA, USA
46. Keating CB, Katina PF (2011) System of systems engineering: Prospects and challenges for the emerging field. Int J Syst Syst Eng 2(2/3):234–256
47. Keating CB (2014) Governance implications for meeting challenges in the system of systems engineering field. Paper presented at the IEEE system of systems engineering conference, Adelaide, SA
48. Keating CB (2015) Complex system governance: theory to practice challenges for system of systems engineering. In: 2015 10th system of systems engineering conference (SoSE). IEEE, pp 226–231
49. Keating CB, Bradley JM (2015) Complex system governance reference model. Int J Syst Syst Eng 6(1):33–52
50. Keating CB, Katina PF (2015) Foundational perspectives for the emerging complex system governance field. Int J Syst Syst Eng 6(1/2):1
51. Keating CB, Katina PF (2016) Complex system governance development: a first generation methodology. Int J Syst Syst Eng 7(1–3):43–74

52. Keating CB, Katina PF (2019) Complex system governance: concept, utility, and challenges. Syst Res Behav Sci 36(5):687–705
53. Keating CB, Katina PF (2019) Enterprise governance toolset. In: Evolving toolbox for complex project management. Auerbach Publications, pp 153–181
54. Keating CB, Bradley JM, Katina PF, Jaradat REM (2017) A systems theoretic-based framework to discover pathologies in acquisition system governance
55. Keating CB, Katina PF, Bradley JM (2014) Complex system governance: concept, challenges, and emerging research. Int J Syst Syst Eng 5(3):263–288
56. Keating CB, Katina PF, Bradley JM (2015) Challenges for developing complex system governance. In: Proceedings of the IIE annual conference. Institute of Industrial and Systems Engineers (IISE), p 2943
57. Keating CB, Katina PF, Bradley JM (2016) Complex system governance: failure mode effects and criticality analysis application. In: Presented at the proceedings of the 2016 industrial and systems engineering research conference, ISERC, Anaheim, CA
58. Keating CB, Katina PF, Bradley JM, Jaradat RE, Hodge R (2018) Systemic intervention for complex system governance. In: INCOSE international symposium, vol 28, no 1, pp 1534–1548
59. Keating CB, Katina PF, Gheorghe AV, Jaradat R (2017) Complex system governance: advancing prospects for system of systems engineering applications
60. Keating CB, Katina PF, Jaradat RE, Bradley JM, Gheorghe AV (2017) Acquisition system development: a complex system governance perspective. In: INCOSE international symposium, vol 27, no 1, pp 811–825
61. Keating CB, Katina PF, Joiner KF, Bradley JM, Jaradat RM (2018) A method for identification, representation, and assessment of complex system pathologies in acquisition programs
62. Keating CB (2005) Research foundations for system of systems engineering. In: 2005 IEEE international conference on systems, man and cybernetics, vol 3, pp 2720–2725. https://doi.org/10.1109/ICSMC.2005.1571561
63. Keating CB, Bradley JM (2015) Complex system governance reference model. Int J Syst Syst Eng 6(1/2):33–52
64. Mitroff I (1997) Smart thinking for crazy times: the art of solving the right problems. Berrett-Koehler Publishers, Inc., 450 Sansome Street, Suite 1200, San Francisco, CA 94111-3320
65. Keating C, Rogers R, Unal R, Dryer D, Sousa-Poza A, Safford R, Peterson W, Rabadi G (2003) System of systems engineering. Eng Manag J 15(3):36–45
66. Marek C, Bradley J, McGowan J, Cui Q (2021) A governance model and safety management system framework for industrial fire safety during naval ship maintenance availabilities. In: Proceedings of the eighteenth annual acquisition research symposium. Monterey, California, pp 6–25
67. Pyne JC, Keating CB, Katina PF (2016) Enhancing utility manager's capability for dealing with complex issues. Proc Water Environ Fed 2016(8):4207–4232
68. Pyne JC, Keating CB, Katina PF, Bradley JM (2018) Systemic intervention methods supporting complex system governance initiatives. Int J Syst Syst Eng 8(3):285–309
69. Shauger JJ (2016) Introduction to service system governance. Int J Syst Syst Eng 7(1–3):189–206
70. Tatar U (2020) Critical space infrastructure: contributions of complex system governance. Space Infrastruct Risk Resil Gov 57:60
71. Walters D (2016) Leadership issues in governance of complex systems. Int J Syst Syst Eng 7(1–3):130–142
72. Walters D, Moorthy S, Carter B (2014) System of systems engineering and enterprise architecture: implications for governance of complex systems. Int J Syst Syst Eng 5(3):248–262
73. Walters D (2018) Leadership and foresight in complex system governance. Int J Syst Syst Eng 8(3):249–267

74. Yesudas R, Efatmaneshnik M, Joiner K (2019) Identifying focal points in IT project governance using a synthetic and systems thinking approach. In: International conference on complex systems design and management. Springer, Cham, pp 79–92
75. Yuchnovicz DE (2016) Understanding system structural tensions to support complex system governance development methodology. Int J Syst Syst Eng 7(1–3):109–129