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Adrian V. Gheorghe
Old Dominion University

James C. Pyne
Old Dominion University

Joseph Sisti
Old Dominion University

Charles B. Keating
Old Dominion University

Polinpapilinho F. Katina
University of South Carolina - Upstate

See next page for additional authors

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Authors

Adrian V. Gheorghe, James C. Pyne, Joseph Sisti, Charles B. Keating, Polinpapilinho F. Katina, and William Edmonson

CRITICAL SPACE INFRASTRUCTURE: A COMPLEX SYSTEM GOVERNANCE PERSPECTIVE

Adrian V. GHEORGHE[1], James C. PYNE[1], Joseph SISTI[1], Charles B. KEATING[1], Polinpapilinho F. KATINA [2], William EDMONSON[3]

[1] Old Dominion University, Norfolk, Virginia, USA
agheorgh@odu.edu, jpyne@odu.edu, joe23430@icloud.com, ckeating@odu.edu

[2] University of South Carolina Upstate, Spartanburg, South Carolina, USA
pkatina@uscupstate.edu

[3] North Carolina Agricultural and Technical State University, Greensboro, North Carolina, USA
wwedmonson@sadaina.com

Abstract: This paper examines the applicability of Complex System Governance (CSG) to advance the Critical Space Infrastructure field (CSI). CSI encompasses space related hardware, workforce, environment, facilities, and businesses that are necessary for societal well-being. CSI is increasing in importance as more societal serving systems are becoming dependent on CSI to operate. Given this increasing dependence on CSI, societal sectors are increasingly at risk should something go wrong with CSI upon which they depend. CSI has been developing is a fragmented way and lacks coherent organization. CSG is focused on design, execution, and evolution of system functions that provide for communications, control, coordination, and integration of complex systems. CSG provides structure and order to complex systems through a rigorous grounding in systems theory (the axioms and propositions that govern behavior, performance, and structure of complex systems), management cybernetics (the science of organizational structure), and system governance (focused on provision of direction, oversight, and accountability). In this paper the intersection of CSI and CSG is explored with respect to the value that can accrue to both fields through their intersection and joint development. The opportunities that lie at the intersection of these fields are examined. This paper concludes the exploration with a discussion of the implications for movement forward in bringing the value offered by CSG to the governance of space-based critical infrastructures.
Keywords: critical space infrastructure, complex system governance.

INTRODUCTION

The Critical Space Infrastructure (CSI) field is in the formative stages of development. CSI is an emerging domain of systems-of-systems encompassing hardware, workforce, environment, facilities, business and organizational entities, whose loss or disruption can have a significant impact on health, safety, economic and social well-being of any nation (Georgescu et al., 2019). CSI is essential to support ground-based critical infrastructures (i.e., chemical, commercial facilities, communications, critical manufacturing, dams, defense industrial base, emergency services, energy, financial services, food and agriculture, government facilities, healthcare and public health, information technology, nuclear reactors, materials, and waste, transportation, water and wastewater) dependent on space-based capabilities to provide essential services. As such, CSI will require new paradigms, methods, and tools focused on joint engineering of interdependent space infrastructure key assets and key resources. This interdependence spans the holistic spectrum of influences across socio-technical-economic- political dimensions. This document explores the intersection between CSI and CSG for potential contributions to the future well-being of society that is becoming increasingly dependent on effective governance of space assets.

This paper is organized to (1) provide a brief overview of CSI, with emphasis on critical issues facing the field, (2) develop a synopsis of CSG, focused on providing an overview with sufficient details to support the further linkage of CSI to CSG, (3) examine the value added through the intersection of the two fields, suggesting how each field might benefit from development at the intersection. The paper closes with concluding remarks to suggest a viable path forward to accelerate the development.

CRITICAL SPACE INFRASTRUCTURE

Critical Space Infrastructure involves space systems (e.g., hardware, workforce, environment, facilities, business and organizational entities), whose loss or disruption can have a significant impact on the health, safety, economic and social well-being of any nation (Georgescu et al., 2019). The quality of life in modern society depends, to a large degree, on the quality and operability of its infrastructure systems. The notion of critical infrastructure systems has traditionally been limited to agriculture and food, water, public health, emergency services, government, defense industrial base, information and telecommunications, energy, transportation and shipping, banking and finance, chemical industry and hazardous materials, post, national monuments and icons, and critical manufacturing (Fischer et al., 2013; Katina & Keating, 2015). To this end, from a System of Systems perspective, CSI provides an integrative capability for multiple interconnected critical infrastructures (e.g., transportation, health, financial). Interestingly, the 16 critical infrastructure sectors (Fischer et al., 2013) and their research are often limited to individual sector systems. This perspective is shared across governments and industry as well as academia (Georgescu et al., 2019; Gheorghe et al., 2018). However, CSI, although not a formally recognized critical infrastructure sector, is an integral part of infrastructure systems. There is an increasing societal dependence for the critical infrastructure enabling capabilities provided by CSI. The health, safety, economic and social well- being of any nation extends beyond the integrated critical infrastructure systems to include space systems. Space systems (e.g., unmanned air systems, satellites, rockets, space probes, and orbital stations) have become key enablers for a wide variety of commercial, scientific and military applications. To this end a report by the Booz Allen Hamilton company suggests that "satellites will and must be an integral part of the future communications ecosystem" (Acker et al., 2013). Failure of such systems – regardless of the source -- anthropic or natural -- can have an alarming impact and consequences on the public wellbeing, which extends to individuals, business, and government as well as the environment. It comes as no surprise that the suggestion continually brought up is that "failure of these infrastructures… is one of the most important vulnerabilities of modern society" (Acker et al., 2013).

Faced with increasing threats, including space capabilities of the cyber-kind, there is a need for calibration of existing risks and vulnerabilities at different levels (e.g., organizational, local, national, and reginal) and costs for protection of space infrastructure systems (Georgescu et al., 2019). This suggests that the development of infrastructure systems needs to be considered and that traditional infrastructure boundaries need to be extended. Protection of such systems appears as the underlying theme since disruption or destruction would have significant human and economic impact, as well as consequences for trust and national prestige. At the same time, space systems feature their own specificities, such as a very harsh and international operating environment with significant, yet rapidly changing, economic and technological constraints. This suggests it is paramount for utilization of concepts in resilience engineering, vulnerability, susceptibility, fragility, exploration of new policy avenues and the creation of new tools and technologies (e.g., Blockchain technology, AI) to address emerging issues and our increasing human dependence on critical space infrastructures. This presents a large set of entities, activities, and developments that will play a pivotal role in a more purposeful development of CSI to support increasingly interconnected and space dependent infrastructures. This exists beyond the purview of the information and telecommunications critical infrastructure sector. CSG offers an approach that can help to orchestrate the large, diverse, and fragmented set of activities and entities with interests and contributions to development of CSI.

There is no shortage of organizations interested in space systems: both private and public. However, all have their respective roles and responsibilities. For example, while NASA, NOAA, the intelligence agencies, Pentagon, Federal Communications Commission, United Nations, and others are involved in CSI-based initiatives, their missions and goals are different. These entities would benefit from a greater coordination and collaboration of our space-based infrastructure systems and the utilization of CSG to support that integration.

At present, CSI is an emerging field in the early stages of development. At a broad level, CSI is considered to be an emerging domain of systems-of-systems that embraces hardware, workforce, environment, facilities, business, and organizational entities (Georgescu et al., 2019). This field is facing multifaceted challenges and the landscape continues to dynamically and dramatically shift. Several critical and interrelated challenges facing CSI field development can identified. Following previous recitations of the nature of this changing spirit of the modern landscape, four challenges are suggested, based on the previous works on complex system domain challenges (Jaradat et al., 2014; Keating, 2014; Keating et al., 2015; Keating & Katina, 2012; Keating & Katina, 2019).

1. *Increasing Complexity* – as with other fields, CSI is beset with increasing complexity of the systems and problems that demark the field. CSI systems will be subject to more highly interconnected systems, emergence in their behavior/performance, higher levels of uncertainty, incomplete/shifting/fallible knowledge, and exponentially increasing information. While this appears daunting, the future of CSI must support development of capabilities to thrive in these conditions. For example, it would be shortsighted to look at a communication satellite without consideration for the interactions, interconnections, and dependencies that the satellite holds with other infrastructures (ground-based systems, space-based systems).

2. *Contextual Influences* – context can be described as the unique circumstances, factors, patterns, trends, stakeholders, and conditions that enable and constrain the structure, behavior, and performance of a system. The wider view of CSI must consider solutions that exist beyond the "technology first, technology only" considerations. Contextual influences will continue to play a critical role in CSI development, as no space infrastructure exists independent of the context within which it is embedded. For example, for a space-based venture, it would be naive to engage development without an appreciation of the political dimensions that could impact the design, deployment, and execution of the venture.

3. *Ambiguity* – with increasing complexity and contextual influences, there is a corresponding lack of clarity in systems and their context. This lack of clarity exists across the design (arrangement of elements, processes, and functions), execution (the particular style of carrying out or performing the system design), and evolution (the trajectory of change for a system over time) for a space infrastructure. This can create conditions where historically stable approaches and expectations are questionable for continued relevance in producing successful outcomes.

4. *Holistic Nature* – in addition to technical/technology aspects of a space infrastructure, consideration of the human/social, organizational/managerial, policy, political, and informational aspects is important. The range of dimensions is crucial, having the ability to enable or disable space infrastructure. The entire range of considerations for a space infrastructure must be considered within the boundaries of consideration for a system. For example, in consideration of design and development of a space infrastructure it would not advisable to bypass emerging political considerations.

While each of the four dimensions can be problematic, it must also be acknowledged that: (1) they do not operate as independent or mutually independent of one another, and (2) they can, and most likely will, dynamically shift in importance and impact over the life of a space infrastructure.

Given the nature of these impediments, to establish a path forward for CSI, Complex System Governance (CSG) is offered and explored as a highly relevant approach.

COMPLEX SYSTEM GOVERNANCE

There is a growing body of knowledge related to CSG (Keating et al., 2015; Keating & Katina 2019; Keating, 2014; Keating & Katina, 2016). 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." (Keating, 2015).

There are several points of emphasis for understanding the basis for CSG in design, execution, and evolution. First, the design accentuates the purposeful and proactive engagement in the creation of the governance system. While this seems as if it should be a taken-for-granted proposition, it can be suggested that the truly purposeful, holistic, and comprehensive design of governing systems represents the exceptional case, rather than the norm. While the merits of this conclusion might be argued, at this point it suffices to say that, based on the current level of system performance of our complex systems, including CSI, it suggests otherwise. Based on issues propagating all manners and forms of our "manmade"' complex systems, the anecdotal evidence suggests that our systems are not sufficiently serving the needs or expectations intended to enhance societal well-being. For CSI it can be seen that the integrated and purposeful design for governance is not presently being performed.

In addition, 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 CSI, the execution is proposed to be achieved through a multitude of entities and activities. While each of these has merit at an individual level, the collection lacks unity and remains fragmented. In the early stages of field development, fragmentation is both necessary and expected, as the nature of the field is emergent. However, over time, there is an expectation that a field becomes more stable with underlying foundations setting the basis for further development. Early fragmentation is necessary to "cast a wide net" so as not to preclude insightful development by a premature narrowing of the field.

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. By its very nature, evolution 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 that the system remains viable (continues to exist) in both the short-term operational sense that delineates current system existence as well as in the long-term evolutionary sense that positions the system for the future. Taking the long view of CSI development, an evolutionary perspective is essential.

CSG is an emerging field focused on helping systems and their practitioners (owners, operators, designers, performers) to deal more effectively with increasingly complex systems and their problems. In a nutshell, CSG suggests that people 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 the exploration of new and novel thinking and practice for more effectively dealing with difficult complex systems and problems.

CSG 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.

There are nine essential system governance functions (Figure 1) including (1) policy and identity, (2) system context, (3) strategic -monitoring, (4) system development, (5) environmental scanning, (6) learning and transformation, (7) system operations, (8) operational performance, and (9) information and communications (for a detailed explanation see the work of Keating & Katina (2019)). These nine functions 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 ensures the 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 outside 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 design and execution issues of the nine essential system functions. 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 represents the "new normal" for systems and their practitioners and shows no signs of subsiding in the near future.

Although the underlying theory, the concepts and execution of CSG are challenging and beyond the scope of this paper, the essence of CSG is not difficult to gasp. The essence of CSG might be captured in the following paragraph and developed in four points as follows:

Subject to fundamental system laws, all systems perform essential governance functions. System performance is determined by effectiveness in achievement of governance functions consistent with system laws. 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 are:

- *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 are our systems subject to laws. These system laws are always there, non-negotiable, non-biased, and explain system 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 the governance of a system. Every system invokes a set of unique implementing mechanisms (means of achieving governance functions) that determine "how" the 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 laws in performance of governance functions carry consequences.* Irrespective of noble intentions, ignorance, or willful disregard, violation of system laws 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 development of governance functions*. When system performance fails to meet expectations, deficiencies in governance functions can offer novel insights into the deeper sources of failure. Performance issues can be traced to governance function issues as well as violations of underlying system laws. Thus, system development can proceed in a more informed and purposeful mode.

The nine functions (Keating & Katina, 2019) performed in CSG are depicted in Figure 1, and include:

- *Policy and Identity – Metasystem Five (M5)* – focused on overall steering and trajectory for the system. This function maintains the identity and the 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 the 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 facilitating learning based on correcting design errors in the metasystem functions and on metasystem transformation planning.
- *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 the 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.

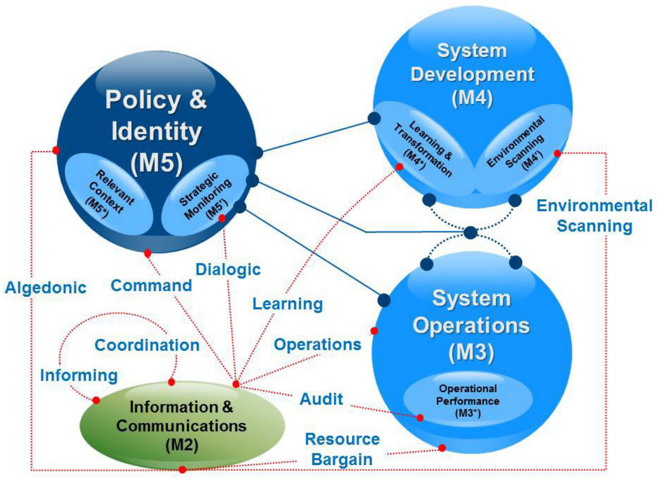

Figure 1. CSG Metasystem Functions

Table 1. 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 and the governed systems
Operations (Metasystem 3)	• Provides for the routine interface focused on near term operational focus • Concentrates 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 • Investigates and reports problematic performance issues within the system • Primarily a Metasystem 3* channel of communication 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 • Provides access throughout the metasystem as well as governed systems
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 • Provides access to entire metasystem and governed systems

Thus, CSG offers a rigorously grounded approach to provide for structured development of a system. The emphasis on generation of communication, control, coordination, and integration provides CSI with an opportunity to purposefully evolve the field and generate support applications.

CONTRIBUTIONS OF CSG FOR CSI

In developing the contributions of CSG for CSI, there are several points of emphasis. First, CSG design accentuates the necessity to purposely and proactively engage in the creation of the governance system. Certainly, in the case of CSI, it can be concluded that it has not been an integrated system, nor is it currently conceived as an integrated system (of systems) requiring purposeful design for integration. While the merits of this conclusion might be argued, at this point, it suffices to say that based on the current level of landscape of CSI, the anecdotal evidence suggests that what we are doing with respect to our integration of CSI as a unity is not working. Second, irrespective of purposeful/purposeless design, execution embodies the notion that a design without deployment offers little more than good intention. For CSI this implies that execution must invoke the design and be subject to evolution of that design as emergent conditions and circumstances dictate design deficiencies. Execution is where a design meets the harsh realities of the 'real world' which is fraught with complexity and emergent conditions that that are sure to test the most thoughtful designs. It should be noted that the need to adjust a system during execution is not an indicative of poor design, but rather a recognition that all designs are flawed. They must be flawed because they are abstractions of real-world complexity that can be neither totally captured nor completely understood. Thirdly, evolution recognizes that systems, as well as their environments, are in constant flux. Therefore, governance must also be able to flex (evolve) in response to internal and external changes impacting the system. Evolution by its very nature suggests that the emphasis is on long-term sustainability, notwithstanding 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 to ensure the system remains viable (continues to exist) in both the short-term operational sense that delineates current system existence as well as in the long-term evolutionary sense that positions the system for the future. For CSI this suggests that a long view should be invoked to appreciate the time horizon of space infrastructure and the need to evolve over that time horizon.

The CSG paradigm and reference model (functions) offer CSI a theoretically grounded framework, corresponding reference model, and explicit functions (and associated communication channels) that can be purposefully designed, executed, and evolved. This instantiation of CSG can provide CSI with a dynamic and holistic model to guide design, execution, and development.

There are several points of emphasis for understanding the basis for CSG in design, execution, and evolution. First, the design accentuates the purposeful and proactive engagement in the creation of the governance system for CSI. Again, while this seems as if it should be a taken-for-granted, it can be suggested that truly purposeful, holistic, and comprehensive design of governing systems represents the exceptional case rather than the norm. While the merits of this conclusion might be argued, at this point it suffices to say that, based on the current level of system performance of our complex systems, including CSI, it suggests otherwise. Based on issues propagating all manners and forms of our "manmade" complex systems, anecdotal evidence suggests that our systems are not sufficiently serving the needs or expectations intended to enhance societal well-being. For CSI it can be seen that the integrated and purposeful design for governance is not presently being performed.

The specific contributions that CSG offers CSI are captured in Table 2.

Table 2. CSG Contributions to CSI

Characteristic	Contribution to CSI
Design, Execution, and Evolution	- Design is the purposeful and deliberate arrangement of the governance system to achieve desirable system performance and behavior. For CSI 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 CSI, execution provides a path for evaluating how effective the execution of the design is in producing the performance/behavior desired from a space infrastructure.
	- Evolution involves the change of the governance system in response to internal and external shifts as well as revised trajectory. For CSI, evolution provides a long view and continual focus on evolving the governing system based on environmental shifts.
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 CSI, the purposeful design of metasystem functions can provide performance that fragmented entities and mechanisms will neither be able to achieve nor maintain.
Communication	- Communication involves the flow, transduction, and processing of information within and outside the system, and provides for consistency in decisions, actions, interpretations, and knowledge creation made with respect to the system. For CSI, 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.
Control	- 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 CS, control suggests that only the constraints necessary to integrate the multiple stakeholders should be invoked. Any excess constraint consumes scarce resources and unnecessarily limits constituent autonomy.
Integration	- Integration represents the continuous maintenance of system integrity. This requires a dynamic balance between the autonomy of constituent entities and the interdependence of those entities, in order to form a coherent whole. This interdependence produces the system identity (uniqueness) that exists beyond the identities of the individual constituents.
Coordination	- 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 CSI, coordination becomes a necessary attribute to ensure that the multiple entities, perspectives, and infrastructures are engaged to prevent unnecessary oscillations and conflicts.
Context	- Context represents the circumstances, factors, patterns, conditions, or trends within which a system is embedded. It acts to constrain or enable the system.
Environment	- Environment aggregates all the surroundings and conditions within which a system operates. It influences and is influenced by a system.

The range of contributions offered by CSG for CSI is varied. Both can benefit from the intersection between these two fields. For CSI, the field receives a conceptually grounded approach to guide more rigorous and accountable design, execution, and evolution of the field. Similarly, CSG benefits by having a demonstrable articulation of the ability of the field to engage a complex domain and provide substantiative value.

CONCLUSION

Advancing CSI is certainly a noble endeavor as more and more people depend on space infrastructure for data transformation. The fragmented landscape of CSI involves multinational perspectives, multidisciplinary development, and multiobjective pursuits. Contributing to the defragmentation and unification of CSI development, CSG is offered as a potential theoretically grounded approach – capable of fostering a greater degree of integration and coordination across disciplines, borders, and entities. CSG can provide for a more rigorous development of control and communications toward a more common purpose. The focus can remain on developing the design, execution, and development of the governance functions such that a more purposeful development of CSI can proceed.

In closing, it might be suggested that CSG is not a panacea for improving the prospects for more effective development of CSI. However, CSG offers a strong systems science-based, engineering-focused, and application-oriented approach to improve practices related to enhanced CSI. There are several opportunities to move the CSG-CSI intersection forward. A multitude of CSI issues continue to emerge across a broad spectrum of concerns. Opportunities and threats span economic, social, organizational, technological, policy, political, security, environmental, and political dimensions. Presently, the design, execution, and development of CSI has been somewhat fragmented (lack of an integrating structure or mapping to holistically understand the issues, entities, and their interrelationships), narrow (issues examined in isolation from other potentially complementary multidisciplinary activities, agencies, and ongoing efforts), and pluralistic (multiple perspectives, tacit assumptions, and developmental objectives subject to divergence and potential conflicts). CSI is driven from multiple stakeholders, perspectives, and competing interests impacting near and long-term sustainability. The application of CSG can have several immediate and substantial impacts on the CSI field.

First, developing a systems-based explanation for the degree of fragmentation (lack of integration) that currently exists in the CSI field will have several benefits, including, (1) identifying redundancies and overlaps with the potential to share knowledge and conserve scarce resource, (2) facilitates natural collaborations by making explicit the structure and organization of the field, and (3) helps to govern multiple different competing perspectives through making them explicit, publicly testing assumptions, and offering insights previously hidden from view. While this does not suggest CSG as a "silver bullet" to cure the ills plaguing CSI development, it does offer a path forward.

Second, the exploration of CSI from the CSG perspective can suggest areas of CSG development necessary to foster greater depths of integration. Also, this might suggest knowledge gaps that need to be closed if the CSI field is to achieve levels of integration sought. Obtaining cues from operational practices can help focus CSG development efforts that cross theoretical/conceptual, methodological, method, and tools/techniques developmental priorities.

Third, the joint development of CSG-CSI can help to *guide the holistic science-based engineering of technologies for applications to enhance effective design, execution, and evolution of CSI for the global community*. Thus, both the CSI and CSG fields can inform, and be informed, by the other field.

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Adrian V. GHEORGHE
Is a Professor of Engineering Management and Systems Engineering and Batten Endowed Chair on System of Systems Engineering in the Department of Engineering Management and Systems Engineering at Old Dominion University, Virginia, USA. He holds an M.Sc. in Electrical Engineering from the Faculty of Power Engineering, Bucharest Polytechnic Institute (Bucharest, Romania), a Ph.D. in Systems Science/ Systems Engineering from City University (London, U.K.), an MBA from the Academy of Economic Studies (Bucharest, Romania), and an M.Sc. Engineering-Economics, Bucharest Polytechnic Institute, (Bucharest, Romania). He has worked with different organizations including the International Atomic Energy Agency (IAEA), the International Institute for Applied Systems Analysis, and the Joint Research Centre of the European Commission.

James C. PYNE
Is a Research Affiliate of NCSOSE in the Department of Engineering Management and Systems Engineering at Old Dominion University, Virginia, USA. He was previously employed at Hampton Roads Sanitation District (Virginia Beach, Virginia), first as a Plant Manager followed by Chief of Design, then Chief of Small Communities. He holds B.S. in Civil Engineering from Virginia Tech (Blacksburg, Virginia), M.S. in Engineering Administration from George Washington University (Washington, D.C.), and Ph.D. in Engineering Management and Systems Engineering from Old Dominion University (Norfolk, Virginia). He has more than 36 years of experience in wastewater management at the technical, managerial and policy levels. His expertise includes Sociotechnical Systems and Complex Systems Analysis. In his role as the HRSD chief of small communities, he has used this knowledge to assist numerous and various stakeholders deal with complex issues.

Joseph A. SISTI
Is a Research Affiliate of NCSOSE in the Department of Engineering Management and Systems Engineering at Old Dominion University, Virginia, USA. He is assigned to the position of Senior Systems Engineer for the Navy Afloat Transport Systems Division within the NIWC LANT organization. He holds a B.S. in Electrical Engineering from Old Dominion University (Norfolk, Virginia) and a M.E.M. in Engineering Management from Old Dominion University (Norfolk, Virginia), and Ph.D. in Engineering Management and Systems Engineering from Old Dominion University (Norfolk, Virginia).

Charles B. KEATING

Is a Professor of Engineering Management and Systems Engineering and the Director for the National Centers for System of Systems Engineering (NCSOSE) in the Department of Engineering Management and Systems Engineering at Old Dominion University, Virginia, USA. He holds B.S. in Engineering from the United States Military Academy (West Point, New York), M.A. in Management from Central Michigan University (Mount Pleasant, Michigan), and a Ph.D. in Engineering Management from Old Dominion University (Norfolk, Virginia). Dr. Keating focuses on teaching and research in the areas of Systems Engineering, System of System of Systems Engineering, Management Cybernetics, and Complex System Governance. His activities have spanned a variety of organizations, including defense, security, aerospace, healthcare, R&D, and automotive. He is a Fellow and Past President of the American Society for Engineering Management and a recipient of society's most prestigious award (the Sarchet Award) in 2015.

Polinpapilinho F. KATINA

Is an Assistant Professor in the Department of Informatics and Engineering Systems at the University of South Carolina Upstate (Spartanburg, South Carolina). He holds B.S. in Engineering Technology, M.Eng. in Systems Engineering, and a Ph.D. in Engineering Management and Systems Engineering, all from Old Dominion University (Norfolk, Virginia). Dr. Katina focuses on teaching and teaching in areas of Complex System Governance, Critical Infrastructures, Engineering Management, Infranomics, Manufacturing Systems, System of Systems, and Systems Pathology.

Dr. William W. EDMONSON

Is a recently retired Professor from the Electrical and Computer Engineering Department at NC A&T State University (NCAT). He received his Ph.D. in Electrical and Computer Engineering from NC State University in 1990. From 2010-19, he was the National Institute of Aerospace (NIA) S.P. Langley Professor working closely with NASA Langley Research Center researchers on small satellite systems focused on advancing the capabilities, functionality, and scope of missions for small satellites, particularly in the areas of free-space optical inter-satellite communication and verifiable model-based systems engineering (includes developing mathematical foundation of systems engineering based on category theory). From 2008-09, he was on an IPA assignment with NASA-Langley Research Center as lead systems engineers for GPS radio occultation instrument and in 2019 was a Fulbright Scholar at the University of Porto, Portugal. Presently, he is collaborating with universities in Ethiopia, Portugal, South Africa, Spain, and Hawaii with research on small satellites and autonomous vehicle development and with aerospace workforce development education programs. Dr. Edmonson serves on the AIAA Small Satellite Technical Committee and is a Senior Member of the Institute of Electrical and Electronics Engineers (IEEE).