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Article

Complex System Governance as a Framework for Asset Management

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Abstract: Complex system governance (CSG) is an emerging field encompassing a framework for system performance improvement through the purposeful design, execution, and evolution of essential metasystem functions. The goal of this study was to understand how the domain of asset management (AsM) can leverage the capabilities of CSG. AsM emerged from engineering as a structured approach to organizing complex organizations to realize the value of assets while balancing performance, risks, costs, and other opportunities. However, there remains a scarcity of literature discussing the potential relationship between AsM and CSG. To initiate the closure of this gap, this research reviews the basics of AsM and the methods associated with realizing the value of assets. Then, the basics of CSG are provided along with how CSG might be leveraged to support AsM. We conclude the research with the implications for AsM and suggested future research.

Keywords: asset management; complex system governance; system viability

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1. Introduction

Twenty-first-century organizations and complex technological installations operate in conditions and environments characterized by a lack of clarity of situational awareness involving overall opaqueness, deep uncertainties, and complexity with large numbers of richly interdependent and dynamically interacting elements. Their behavior and future conditions are difficult or almost impossible to predict accurately. Undoubtedly, these conditions create the context in which risks emerge, and emergent behavior (structure or performance) cannot be deduced from constituent elements and past data. Nonetheless, decisions and actions must be undertaken to enable sustainable business continuity.

In complex technological installations, an emerging preferred approach to coping with the present operating conditions is asset management. Asset management (AsM) has emerged from engineering as a structured approach to organizing complex organizations to realize the value of assets while balancing performance, risks, costs, and opportunities [1–3]. While AsM can be traditionally viewed as "doing things to assets" [1] (p. 8) using concepts such as risk management and reliability, it actually encompasses more to include a holistic view of organizations. To this end, the ISO Technical Committee for Asset Management Systems, ISO/TC251, clarifies the difference between Managing Assets and Asset Management [4]. For example, while it is true that for years people, organizations, and enterprises developed whole disciplines to help define the best ways to nurture assets through their useful lives, the introduction of the formal discipline of "Asset Management" assures the derivation of value for the organization and not just promoting the best for asset care.

However, AsM is not a panacea for all issues associated with assets in the 21st century. First, contemporary organizations operate in a flux environment. A flux environment includes elements of market, natural, technical, technological, organizational, regulatory, legal, political, and financial systems, all affecting organizations. Additionally, modern enterprises are themselves complex systems marked by a range of technical, human, social, organizational, managerial, political, policy, and information considerations [5].

Furthermore, there are significant uncertainties connected to complex systems. Two types of uncertainties are often taken into account [6,7]:

- Aleatory uncertainty—uncertainty arising when an event occurs randomly. It can be expressed in terms of probability or frequency. For example, a random equipment failure is considered aleatory uncertainty. Interestingly, this type of failure can have a predictable rate and occur at an unpredictable (i.e., random) time.
- Epistemic uncertainty—typically referred to as a state-of-knowledge uncertainty, epistemic uncertainty has three sub-categories: parameter, model, and completeness uncertainty. Epistemic uncertainty arises when one makes statistical inferences from data and/or from incompleteness in the collective state of knowledge. Those uncertainties relate to the degree of belief that an analyst has in the representativeness or validity of a model and its predictions.

Complex organizations face both types of uncertainties and often address these issues by using various models and tools to help decrease uncertainties and quantify risks in their asset management decision-making process. However, the traditional models and tools have limitations [2,8]. These limitations affect the utility of traditional methods (e.g., risk management). Even more concerning is using conventional methods in AsM without considering the potential impact of conventional technique limitations [9]. Therefore, deriving value for organizations in the 21st century must be holistic and beyond the traditional concept of asset care.

Therefore, this study aims to explore how the domain of AsM can leverage the capabilities of CSG, an emerging area of research with a comprehensive framework for effective system performance. To fulfill this goal, the remainder of this article is organized as follows: Section 2 is a literature review of AsM in different industries. Section 3 is a description of CSG. Section 4 develops implications of CSG for AsM. The article concludes with suggested areas of research.

2. Literature Review: Asset Management

Various industries have embraced the concept of AsM. This section provides a summary of these efforts. For example, significant efforts have been devoted to asset management particularities tailored to the industry in the nuclear power industry. Specifically, this industry has developed the nuclear asset management (NAM) and risk-informed asset management (RIAM) processes. These efforts are aimed at guiding operational, resource allocation, and risk management decisions at different levels of business operations to maximize nuclear power plant value to stakeholders while maintaining public and plant staff safety [10].

The concepts of AsM are also prevalent in transportation. For example, Heiner and Kockelman [11] provide a literature review of related right-of-way acquisition and property valuation. Heiner and Kockelman [11] describe the appraisal process and the influence of federal law on acquisition practices and provide hedonic-price models for estimating costs associated with taking property using recent acquisition data from several Texas corridors and full-parcel commercial sales transactions in Texas' largest regions. A summary of literature on AsM practices at U.S. State Departments of Transportation can be found in a report commissioned by the Texas Department of Transportation [12].

However, the concepts of AsM are unique to nuclear power plants and transportation systems. AsM concepts are found in petrochemicals [13,14], power generation, transmission and distribution [15], and infrastructure management [16]. Therefore, AsM concepts permeate routine organizational activities, including finance, planning, engineering, personnel, and information management to assist agencies in managing assets cost-effectively [17]. Again, this resonates, given that the aim of AsM is not "asset care" but rather "management of assets." Moreover, Nemmers [18] suggests that asset management's main objective is to improve decision-making processes to ensure the "best" possible return on investment is obtained. However, the term "best" possible return is a relative tern due to the asset systems' complexity, environment, and interplay.

Nonetheless, to achieve the objective of improved decision-making to maximize return on investment, AsM must embrace all of the processes, tools, and data required to manage assets effectively [18]. Thus, frameworks for effective utilization of resources are needed. Furthermore, such frameworks must effectively carry out this process, encompassing the entire organization, environment, and interplay. An example of such a framework is the risk-informed decision-making (RIDM) model in asset management. RIDM is a structured and rational decision-making methodology in AsM. As a methodology, RIDM contains three key phases (see Figure 1): (i) setting the framework, (ii) performing detailed analyses, and (iii) conducting global analysis, deliberation, decision-making, communication, and implementation:

- Setting the framework—this phase ensures an adequate description of asset issues, context, alternatives, decisions, and potential methodologies. Setting the framework is comparable to 'problem formulation' and related to the overall system success. This phase is often referred to as "probably the single most important routine, since it determines in large part . . . the subsequent course of action" [19] (p. 274).
- Performing detailed analyses—this phase involves performing required detailed analyses and is often carried out by subject matter experts (SME) and analysts using appropriate methods, models, and tools suggested and defined in the first phase. This phase aims to produce results, inputs, and insights and formulate recommendations for the decision-maker. These analyses have to be rigorous and systematic as well as being technically and scientifically sound.
- Conducting global analysis, deliberation, decision-making, communication, and implementation—performed by the decision-maker and supported by SMEs, analysts, and stakeholders. This phase is qualitative and aims to grasp all relevant insights, high-level analysis, and deliberation results. Decision makers have to make extensive use of various quantitative analyses methods with the level of details appropriate for the decision to be made and integrated with other relevant influence factors, often intangible and intangible.

Once deliberations are completed and decisions are made, it is necessary to ensure that the organization has the resources needed for implementation. Thus, with the main elements of the RIDM in AsM defined, an enhanced decision-making framework emerges.

The above discussion is provided for two reasons: First, the domain of AsM is well-accepted, as indicated by ample industries and modes of deployment. Secondly, AsM, like many other domains, benefits from cross-fertilization, as indicated by the use of methods from different disciplines, e.g., risk management. Therefore, there remains a need for AsM to leverage capabilities in emerging research, including CSG. The latter is the basis for the remainder of this article.

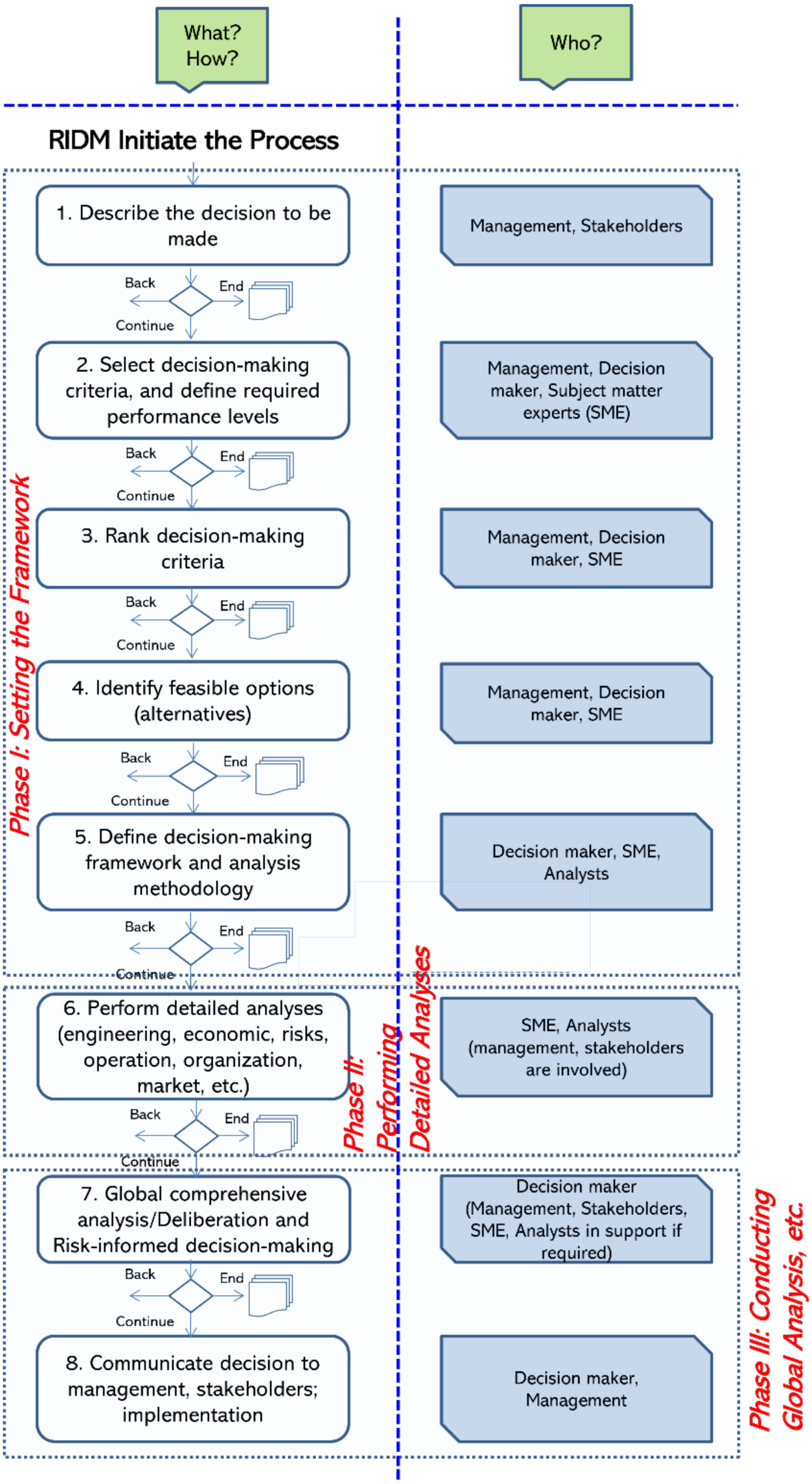

Figure 1. A summary of RIDM framework, modified from Komljenovic et al. [9] (p. 205).

3. CSG: Complex System Governance

Complex system governance (CSG) is an emerging field, representing an approach to improving system performance through the purposeful design, execution, and evolution of nine essential metasystem functions that provide for the control, communication, coordination, and integration of a complex system. CSG was developed at the National Centers for System of Systems Engineering and is anchored in General Systems Theory and Management Cybernetics. It emphasizes the effective performance of metasystem functions necessary to maintain system viability (see, e.g., [20,21]). A methodology, according to Jackson [22], is a set of "procedures for gaining knowledge about a system and structured processes involved in intervening in and changing systems" (p. 134). Interestingly, there is no shortage of methodological approaches used to explore and gain knowledge about systems. Table 1 provides a summary of systems-based methodologies. Interested readers are directed to Jackson [23] and Katina [24] for more extensive discussions. However, suffice to say that selection and use of a specific methodological approach will depend on the nature of the problem and system at hand as well as the purpose of the analysis [25]). Moreover, issues of ontology and epistemology should not be ignored, especially when dealing with complex situations [26].

Notwithstanding CSG expertise, the authors include the above systems-based methodologies to indicate the need for further exploration of AsM in systems-based methodologies. However, given the goal of the present research, we focus on how AsM can leverage CSG capabilities.

As a field, CSG has been described as the "design, execution, and evolution of the metasystem functions necessary to provide control, communication, coordination, and integration of a complex system" [20] (p. 264). This emerging field has its foundations in GST's aspect of laws, principles, and theorems used for understanding the structure, behavior, and performance of complex systems [51–53] and management cybernetics, which has been described as the science of effective organization [35,54–56]. Keating and Bradley [57] provided "a systemic representation [a reference mode] of CSG, built upon the intellectual foundations of systems theory and management cybernetics. The purpose of the reference model is to provide an organizing construct for the interrelated functions necessary to perform CSG" (p. 41).

There are four elements of CSG. The first element essential to understanding CSG is the metasystem construct. The metasystem construct brings several vital considerations of CSG development, including [58]:

- operating at a logical level beyond the system(s)/subsystems/entities as elements that it must integrate.
- Being conceptually grounded in the foundations of general systems theory (axioms and propositions governing system integration and coordination) and management cybernetics (communication and control for effective system organization).
- a set of interrelated functions, which only specify 'what' must be achieved for continuing system viability (existence), not specifying 'how' those functions are to be achieved
- functions that must be minimally performed if a system is to remain viable—this does not preclude the possibility that a system may be poorly performing yet still continue to be viable (exist).
- a system that is purposefully designed, executed, and maintained, or left to its own (self-organizing) unstructured development

The importance of the metasystem is its function as a 'governor' in the cybernetic sense of providing control for a system—ensuring the system maintains stability (performance) in the midst of internal system flux and environmental turbulence. In essence, *the primary function of control by the metasystem in CSG is to provide the minimal constraint necessary to ensure continued system performance and behavior.* In this sense of control, the maximum level of autonomy is reserved for the 'governed' systems/subsystems. This is achieved by only implementing the (minimal) constraints necessary to provide sufficient stability that ensures system performance levels can be maintained. The achievement of this stability is accomplished through the metasystem's ability to provide sufficient regulatory capacity. This regulatory capacity mitigates the turbulence generated from the environment as well as the flux generated internal to the larger system. In addition, this regulatory capacity seeks to provide the highest degree of autonomy possible to the systems/subsystems being governed. The metasystem provides only the control (constraint) necessary to integrate the entities (systems or subsystems) to support the larger purpose (performance/behavior) expected of the system. Keating et al. [20] posit that control generated by the metasystem is achieved in conjunction with three other primary roles for CSG: communication, coordination, and integration, described in Table 2.

Table 1. Systems-based methodologies.

Methodology	A Brief Description of Methodology
Systems analysis	This methodology is largely dependent on feedback loops and black boxes of cybernetic management. It aims to optimize sociotechnical systems based on fixed parameters such as cost and benefits. Systems analysis includes a number of phases discussed elsewhere [27,28].
Systems engineering	This approach places emphasis on defining technical and business customer needs with the goal of producing quality products that meet user needs. A generic life-cycle model for systems engineering along with its stages is discussed elsewhere [29,30].
Operations research	This approach is commonly associated with determining maximum (or minimum) variable (e.g., profit, performance, yield, loss, risk) inventory, allocating, waiting time, replacement, competitive, and combined processes. Operations research was developed to deal with complex organizations that are under the control of management [31,32]. A generic model associated with this approach is discussed elsewhere [31,32].
System dynamics	System dynamics is concerned with limits of growth and understanding of the system structure using feedback loops as the main determinants of system behavior. Mathematical in nature, system dynamics involves four major variables: the system boundary, network of feedback loops, variables of 'rates' or 'flows' and 'levels' or 'stocks', and leverage points [33,34].
Organizational cybernetics	Organizational cybernetics embodies the idea that organizations are black boxes characterized by complexity, self-regulation, and probabilistic behaviors. Central to this approach is the viable system model, which is based on the neurocybernetic model, consisting of five essential subsystems that are aligned with major viable organizational functions. The viable system model [35] is a model rather than a methodology as it does not have a clear set of prescribed phases for deployment. However, two general stages of system identification and system diagnosis are discussed elsewhere [23].
Strategic assumption surfacing and testing	This approach is grounded on the premise that the formulation of the correct solutions to the right problem requires uncovering critical assumptions underlying policy, plan, and strategy. The articulation of critical assumptions should enable management to compare and contrast and gain new insights on their assumptions when dealing with a 'wicked' situation [36].
Interactive planning	Developed by Russell L. Ackoff, this methodology focuses on creating a desired future by designing present desirable conditions. It is made up two parts: idealization and realization. These parts are divisible into six interrelated phases [37].
Soft systems methodology	Attributed to Peter Checkland and his colleges at Lancaster University, this methodology emerged as a response to a need for methods that can be used to intervene in 'ill-structured' problem situations where it is important to learn about systems while still focusing on 'goal-seeking' endeavors that answer 'what' should be done and 'how' it should be done [23]. Checkland [38] suggests that understanding context was largely ignored in systems engineering. His research was aimed at providing a more rigorous attempt to tackle problematic situations through addressing issues such as context.
Systems of systems engineering methodology	This methodology is intended to provide a high-level analytical structure to explore complex system problems [39]. Proponents of this approach suggest that enhancing our understanding of complex systems requires a "rigorous engineering analysis [System of Systems Engineering Methodology] that invests heavily in the understanding and framing of the problem under study" [39] (p. 113). In the research of DeLaurentis et al. [40], a three-phase approach (i.e., defining the SoS problem, abstracting the system, modeling and analyzing the system for behavioral patterns) is suggested. However, Adams and Keating [39] and Adams and Meyers [41] suggest a seven (7)-stage process, which consists of twenty-three (23) constituent elements.

Table 1. *Cont.*

Methodology	A Brief Description of Methodology
Critical systems heuristics	Developed by Werner Ulrich, this methodology is concerned with 'unfairness in society' [23]. This approach promotes emancipatory systems thinking for planners and citizens alike. Synonymous with this methodology are three phases [42].
Organizational learning	Developed by Chris Argyris and Donald Schön, this methodology is concerned with single-loop and double-loop learning where management of the organization can contrast 'expected outcomes' with the 'obtained outcomes'. Contrasting these outcomes involves learning based on errors discovered during single-loop learning and provides the basis for modifying organizational norms, policies, and objectives [43]. A key premise of this methodology is that learning and adapting new knowledge must be generated at the individual as well as at organizational levels [44,45].
Sociotechnical systems	Attributed to Eric Trist, Ken Bamforth, and Fred Emery and their work at the Tavistock Institute in London, this methodology is concerned with a joint optimization of both social/soft (including human) and technical aspects of organizations [46]. This methodology involves several steps as postulated by Pasmore [46] for redesigning sociotechnical systems [47].
Total systems intervention	Developed in the early 1990s by Robert Flood and Michael Jackson, this meta-methodology emerged out of the recognition of strengths of capabilities of individual systems approaches, the need for pluralism in systems thinking, and calls for emancipatory ideas in systems thinking, in reference to critical systems thinking [23]. This methodology is based on the premise that contemporary systems-based methodologies are not complementary. Laszlo and Krippner [48] thus suggested that a successful complex organizational intervention might require a 'combination' of any set of systems-based approaches. This methodology is underpinned by principles of complex situations and consists of three phases of creativity, choice, and implementation [49,50].

Table 2. Metasystem control components with implication for AsM.

Metasystem Control Component	Component Description	Implications for AsM
Communication	The flow, transduction, and processing of information within and external to the system, which provides consistency in decisions, actions, interpretations, and knowledge creation made with respect to the system.	AsM provision for the flow, transduction, and processing of information among different assets and their environment to enable consistent decisions, actions, interpretations, and knowledge creation.
Coordination	Providing for interactions (relationships) between constituent entities within the system and between the system and external entities, such that unnecessary instabilities are avoided.	AsM provision for interactions (relationships) between constituent asset systems/subsystems within the system and between the organization and external assets such that unnecessary instabilities are avoided
Integration	Continuous maintenance of system integrity. This requires a dynamic balance between the 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.	AsM provision for continuous maintenance of system integrity. This requires a dynamic balance between the autonomy of constituent assets and the interdependence of those assets to form a coherent whole. The coherent whole produces a unique organizational identity beyond the identities of the individual assets.

The second element of CSG involves the nine governance functions of the metasystem, including four primary functions and five subfunctions. The metasystem functions find the intellectual roots in Beer's work [35,54,55] in management cybernetics and the viable system model. These interrelated governance functions must be performed if a system is to remain viable (continue to exist) under conditions of internal flux and external turbulence. In summary, the nine metasystem functions included in the metasystem for CSG include:

- ***Policy and Identity—Metasystem Five (M5)***—focused on overall steering and trajectory for the system. Maintains identity and defines the balance between current and future focus. *For AsM, M5 ensures the overall maneuvering and course of the organization, ensuring a balance between current and future asset management for the organization.*
- ***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, patterns, or trends that enable or constrain the execution of the system. *For AsM, M5* ensures that the organization is accounting for the set of circumstances, factors, conditions, patterns, or trends that enable or constrain the utility of assets.*
- ***Strategic System Monitoring—Metasystem Five Prime (M5′)***—focused on oversight of the system performance indicators at a strategic level, identifying system-level performance that exceeds or fails to meet established expectations. *For AsM, M5′ ensures the oversight of the asset performance indicators at a strategic level, identifying asset system-level 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. *For AsM, M4 ensures that the organization maintains the models of the current and future asset systems while concentrating on the organizations' long-range developments 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 the transformation of the metasystem. *For AsM, M4* ensures that the organization has learning capabilities, especially based on correction, to enable the design and planning necessary for organizational transformation related to assets.*
- ***Environmental Scanning—Metasystem Four Prime (M4′)***—designs, deploys, and monitors the sensing of the environment for trends, patterns, or events with implications for both present and future system viability. For AsM, M4′ ensures that the asset management organization designs, deploys, and monitors the sensing of the environment for trends, patterns, or events with implications for both present and future system asset 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. *For AsM, M3 ensures that the organization has the means to address the day-to-day asset management activities to meet the established performance levels.*
- **Operational Performance—Metasystem Three Star (M3*)**—monitors system performance to identify and assess aberrant conditions, exceeded thresholds, or anomalies. For AsM, M3* ensures that the organization can monitor asset system performance to identify and evaluate anomalous conditions, exceeded thresholds, or anomalies.
- ***Information and Communications—Metasystem Two (M2)***—designs, establishes, and maintains the flow of information and consistent interpretation of exchanges (through communication channels) necessary to execute metasystem functions. For *AsM, M2 ensures that the organization is designed to maintain the flow of information and that consistent interpretation of exchanges (through communication channels) can be achieved.*

Figure 2 provides a graphic depiction of the interrelationship between the functions and subfunctions of the metasystem. It is important to note that the metasystem functions (i) do not operate independently and instead are interrelated functions and (ii) are performed by mechanisms (artifacts that permit achievement of the specific function) and that (iii) execution determines the level of governance effectiveness and ultimately system performance.

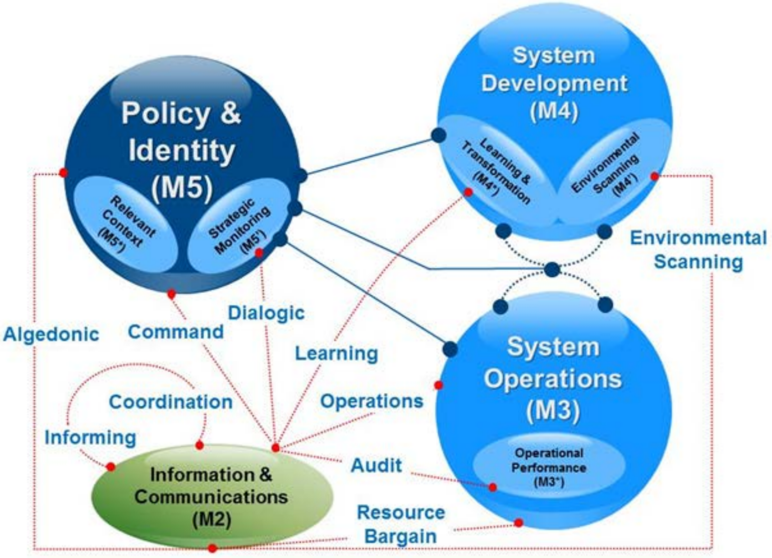

Figure 2. Interrelated metasystem functions and communication channels, adapted from Keating and Katina (2016, p. 50).

The set of communication channels that provide for the flow of information and consistency in interpretation for exchanges within the metasystem and between the metasystem and external entities form the third core element of CSG. The ten communication channels are adapted from the work of Beer [35,54,55] and extensions of Keating and Morin [59] and Keating and Katina [58]. Table 3 provides a summary of the communication channels and their primary AsM metasystem function responsibility, and the particular role they play in AsM metasystem execution.

Again, the essence of this section is that (1) all complex systems that exist must minimally perform the metasystem functions, (2) the metasystem functions identify 'what' must be achieved, not 'how' it must be achieved (by specific mechanisms), and (3) the performance of the metasystem functions and their associated communication channels determines the level of system performance achieved. For AsM, this summation suggests reaffirmation of the need to (i) know organizational asset metasystem functions, (ii) acknowledge that the mere presence of the AsM Metasystem functions does not assure the performance of an asset management organization, and (iii) finally, the performance of AsM metasystem functions is a function of effective use of metasystem functions and communication channels.

The fourth essential foundational element of CSG leans on the relationship between the metasystem and governed systems. For AsM, the metasystem must provide for communications, control, integration, and coordination among the different governed asset systems. In this case, the asset systems can be complex in their own right (but seen as subsystems from the AsM Metasystem vantage point), hence a need for an AsM Metasystem. The AsM metasystem for the more extensive system(s) must also act to ensure the overall system performs as a unity to produce value that is consumed external to the system. In effect, the performance of the governance functions allows the entire system to work as a unity. This permits the establishment and maintenance of system coherence (identity) and cohesion (unity). At the most visceral level, the metasystem keeps the system from either collapsing from external pressures or flying apart from internal forces. Figure 3 provides a logical separation of the AsM metasytem and the governed asset systems.

Table 3. Metasystem communication channels and implication for AsM.

Metasystem Communication Channels	A Brief Description of the Function of the Communication Channel in the Context of AsM
Command (Metasystem 5)	• Provides non-negotiable direction for AsM metasystem and governed asset systems. • Primarily flows from the AsM M5 and disseminated throughout the system (i.e., asset systems).
Resource bargain/ accountability (Metasystem 3)	• Determines and allocates the resources (e.g., manpower, material, money, information, support) to governed asset systems. • Defines performance levels, responsibilities, and accountability for governed asset systems. • Primarily an interface between M3 to the governed asset systems.
Operations (Metasystem 3)	• Provides for the routine interface concerned with near term operational focus. • Concentrated on providing direction for system production of value (products, services, processes, information) consumed external to the system. • Primarily an interface between M3 and governed asset systems.
Coordination (Metasystem 2)	• Provides for AsM metasystem and governed asset systems balance and stability. • Ensures design and achievement of design and execution of (1) sharing of information within the organization necessary to coordinate activities and (2) ensures the decisions and actions necessary to prevent disturbances are shared within the AsM metasystem and governed asset systems. • Primarily a channel designed and executed by M2.
Audit (Metasystem 3*)	• Provides routine and sporadic feedback concerning operational performance. • Investigation and reporting on problematic performance issues within the organization. • Primarily a M3* channel for communicating between M3 and governed asset systems concerning performance issues.
Algedonic (Metasystem 5)	• Provides a ‘bypass’ of all channels when the integrity of the system is threatened. • Compels an instant alert to crisis or potentially catastrophic situations for the system. • Directed to M5 from anywhere in the AsM metasystem or governed asset systems.
Environmental Scanning (Metasystem 4′)	• Provides a design for sensing of the external organizational environment. • Identifies environmental patterns, activities, trends, or events with organizational implications. • Provided for access throughout the AsM metasystem as well as governed asset systems by M4′.

Table 3. *Cont.*

Metasystem Communication Channels	A Brief Description of the Function of the Communication Channel in the Context of AsM
Dialog (Metasystem $5'$)	• Provides for examination of organizational decisions, actions, and interpretations for consistency with system purpose and identity. • Directed to M5 from anywhere in the AsM metasystem or governed asset systems.
Learning (Metasystem 4*)	• Provides detection and correction of error within the AsM metasystem as well as governed asset systems, focused on system design issues as opposed to execution issues. • Directed to M4* from anywhere in the AsM metasystem or governed asset systems.
Informing (Metasystem 2)	• Provides for flow and access to routine information within the AsM metasystem or between the AsM metasystem and governed asset systems. • Access provided to the entire AsM metasystem and the governed asset systems.

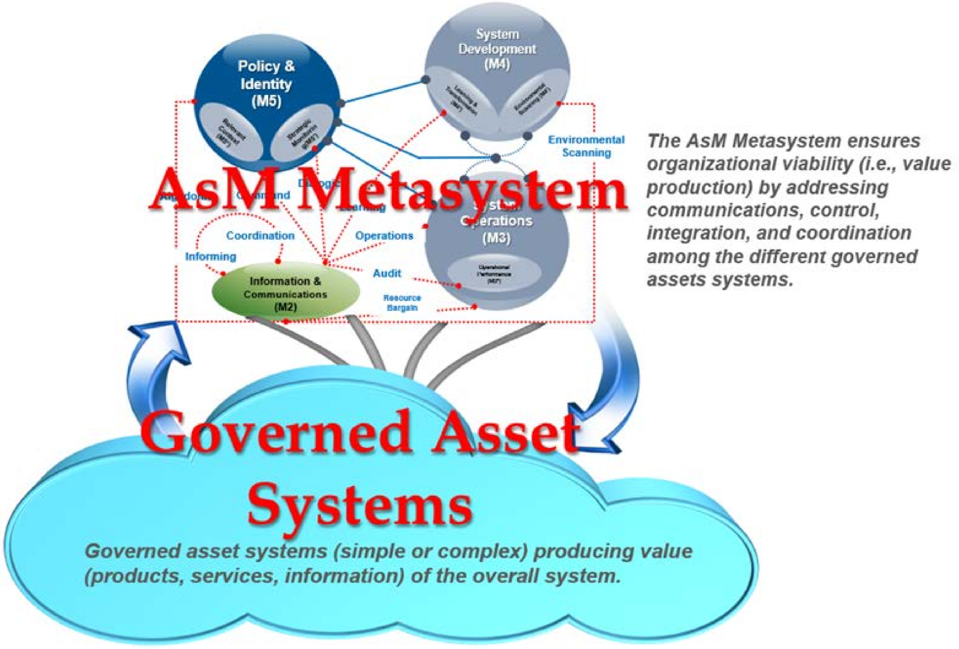

Figure 3. The relation of the AsM Metasystem and the governed asset systems.

At this point, we have established the value proposition associated with the inclusion of CSG, especially the concepts of metasystem functions and communication channels in AsM. To further close the AsM-CSG gap, we provide the following observation on the risk-informed decision-making (RIDM) model in asset management. Again, RIDM is a structured and rational decision-making methodology in AsM and contains three phases. Table 4 provides the first iteration of a summary of three phases on RIDM contrasted with CSG's development methodology [58].

Table 4. A comparison of RIDM and CSG development methodology [58].

RIDM Phase	RIDM Phase Description	Corresponding Phase in CSG Development [58]
Setting the framework	Ensuring an adequate description of asset issues, context, alternatives, decisions, and potential methodologies.	Initialization—initial understanding of the situation through two primary facets: (i) establishing the nature and structure of the system of interest and (ii) exploring the context within which the system of interest is embedded.
Performing detailed analyses	Performing required detailed analyses and often carried out by subject matter experts (SMEs) and analysts using appropriate methods, models, and tools suggested and defined in the first phase. This phase aims to produce results, inputs, and insights and formulate recommendations for the decision-maker. These analyses have to be rigorous, systematic, and technically and scientifically sound.	Readiness Level Assessment—the aim is to answer the question, 'What do the different artifacts from initialization suggest for the state of system governance and implications for development?'. A deep introspection by the system practitioners is needed to (i) appreciate the current state of governance and (ii) establishment of sets of feasible CSG development activities.
Deliberation, decision-making, communication, and implementation	Performed by the decision-maker and supported by SMEs, analysts, and stakeholders. This phase is qualitative and aims to grasp all relevant insights, high-level analysis, and deliberation. The decision-maker has to use various quantitative analyses with the level of detail appropriate for the decision to be made and integrate other relevant influence factors, often tangible and intangible.	Governance Development—this third stage identifies the feasible activities that will be engaged in support of CSG development. However, feasibility is a function of the state of CSG and the corresponding 'classes' of development activities that are compatible with that classification of CSG

Clearly, rather than competing methodologies, RIDM and CSG development methodology are complementary approaches to understanding systems. While each phase will produce different knowledge, especially based on applications, Table 4 shows overlapping similarities. For example, each phase feeds into the next. In CSG, a rigorous understanding of the system and its context (i.e., initialization) provides a foundation for the second stage of CSG development (i.e., governance readiness level, GRL) assessment, which is similar to the "setting the framework" and "performing detailed analyses" phases of RIDM.

4. CSG Implications for AsM and Conclusions

In this article, we have established means to embedding CSG in AsM, especially the concepts of metasystems functions and CSG development methodology. This approach is designed to provide a guide to support the design, execution, and evolution of AsM. Ultimately, AsM would need to address practitioners' (owners, operators, performers, and designers) issues.

However, in making this leap, CSG for AsM should not be seen as a panacea for all problems facing the management of governed asset systems. Instead, CSG is advocated for as an emerging field with a significant opportunity to provide value in the following AsM areas:

- ***Enhancing the capacity of individual practitioners of AsM can increase their ability to engage AsM problems***. The presented message is grounded in systems thinking. Effectiveness in dealing with AsM is achieved through development and propagation of CSG language, methods, and tools to assist practitioners in their efforts to design, analyze, execute, and evolve complex systems and their associated problems. These problems are a byproduct of modern enterprises and their systems. A certain level of thinking in systems is necessary to deal with the entire range of complex system problems more effectively.
- ***Developing competencies at the organizational level for dealing with AsM as complex systems and their derivative problems.*** This involves the generation of knowledge, development of skills, and fostering abilities beyond the individual level to embrace problems holistically. For AsM, holism suggests competency development that expands beyond narrow technology-centric solutions. Instead, enhanced organizational competencies span the entire range of sociotechnical considerations endemic to AsM, as articulated in CSG development efforts.
- ***Assessment of asset infrastructure compatibility necessary to support systems-based endeavors.*** This compatibility is essential to formulate contextually consistent approaches to problems, create the conditions required for governance system stability, and produce coherent decisions, actions, and interpretations at the individual and organizational levels. The most exceptional system solutions, absent compatible supporting asset infrastructure, are destined to underachieve in the best-case scenario or outright fail in the worst-case scenario. It is systemically naïve to think that CSG-based initiatives can be developed and deployed independently of the governed asset infrastructure systems.
- ***Identification of governance readiness level***. Governance readiness level identification can help establish the current state of CSG for AsM and the nature and type of feasible initiatives that can be undertaken with confidence in their successful achievement. This does not limit the severity (or number) degree of inadequacies in a system. However, it does force careful consideration concerning what might be reasonably 'taken on' as initiatives to advance the state of governance. This consideration is based on the current state of CSG performance, the limiting/enabling context, and the degree of CSG maturity that would be required of different proposed development initiatives. Minimally, exploration of the CSG readiness level can provide new insights into past successes/failures as well as cautions for impending future endeavors.
- ***Explicit models for understanding structural relationships, context, and systemic deficiencies.*** Explicit models for understanding, generated through CSG efforts, can

provide insights into the structural relationships, context, and systemic deficiencies that exist for AsM. These insights can accrue regardless of whether or not specific actions to address issues are initiated. The models can be constructed without system modification. Therefore, alternative decisions, actions, and interpretations can be selectively engaged based on the consideration of insights and understanding generated through modeling efforts.

- ***Purposeful governance development for AsM system viability***. Purposeful governance development through focused design, analysis, and evolution of the CSG functions necessary to maintain AsM viability is possible. While all viable (existing) systems perform the CSG functions, it is rare that they are purposefully articulated, examined, or developed in a comprehensive fashion. Purposeful CSG development can produce a 'blueprint' against which development can be achieved by purposeful design, rather than serendipity. This includes the establishment of a set of 'dashboard indicators' for CSG AsM performance. These performance indicators exist beyond more 'traditional' measures of system/organizational performance and can more appropriately track the evolution of CSG governance and AsM performance.
- ***Coherent strategic decision support can be achieved by 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. In light of CSG development priorities, low contribution efforts can be eliminated and resources shifted appropriately.
- ***Rigorous guided 'self-study' into CSG can provide significant insights into how the system actually functions.*** Although enterprises and their systems function routinely and successfully on a daily basis, as a matter of course, practitioners are not particularly skilled, nor do they engage, in deep reflection as to why, how, and what they do from a systems point of view. The gains to be made by reflective self-examination, from a systemic point of view, can reveal insights far beyond traditional methods of examination (e.g., Strategic Planning, SWOT analysis, etc.). Thus, practitioners can examine a different level of analysis through 'self-study' and experience insights in a "safe-to-fail" setting. Additionally, self-study might suggest the level of education/training necessary for individuals and the organization to increase individual capacity and organizational competence for systems thinking essential to CSG development.

CSG development value can span practitioner, enterprise, support infrastructure, context, and system levels. The specific achievement of value is certainly dependent on the degree to which an individual, enterprise, or system is willing to engage in the development effort. However, value is not limited to an 'all or nothing' application of CSG. There is much to be gained in even small endeavors within the larger framework of CSG development. For instance, training in systems thinking can provide insights and improve the capacity of AsM practitioners to 'think systemically'. Thus, individuals might be better prepared to understand the sources of systemic issues and enhance the potential for alternative responses to more effectively deal with increasing complexity.

Ultimately, CSG seeks to increase the probability of achieving desirable system performance (viability, growth, etc.) in response to internal system flux and external environmental turbulence. In such an environment, there remains a need to consider dimensions of methodology (generalized frameworks defining what must be done, ranging from idiographic—specific and unique to nomothetic—general and consistent), epistemology (views on the nature of knowledge ranging from anti-positivism—knowledge is subjective and constructed to positivism—knowledge is objective and absolute), ontology (views on the nature of reality ranging from nominalism—accepts a constructed reality to realism—accepts that reality is objectively known), and the nature of human beings (the degree to which free will exists ranging from voluntarism—there is free will of humans to determinism—available actions are predetermined) when addressing problems and to search for solutions in AsM (Figure 4).

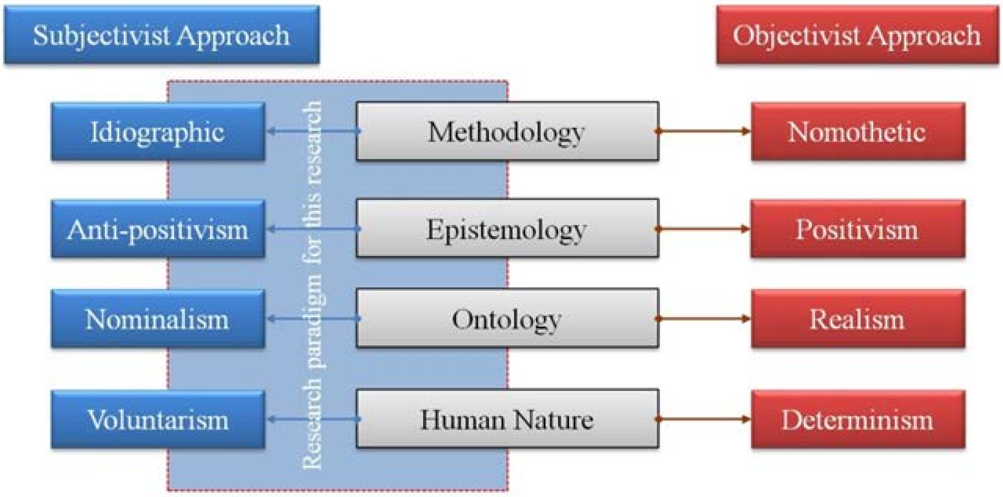

Figure 4. Grounding AsM research in research paradigm, adapted from Burrell and Morgan [60].

While improving the management of assets using concepts of governance of the complex system, especially advancing the state of design, execution, and evolution of the nine metasystem functions and communication channels for assurance of continued system viability, remains reasonable, there remain opportunities to address CSG knowledge claims along philosophy dimensions related to the value of assets.

Moreover, extending the above, when dealing with AsM, there is a need to account for quality attributes. Quality attributes (e.g., affordability, composability, dependability, degradability [61], extendibility, interoperability, learnability, reliability [62], scalability, serviceability, susceptibility testability, vulnerability, etc.) form the 'ilities' [63] that can be realized as non-functional requirements that can be used to enhance performance of AsM. There remains a need for research articulating CSG's role in the realization of 'system ilities'.

Finally, we suggest engagement in case applications of the suggested utility of CSG in AsM. Case studies are appropriate when there is a unique or interesting story to be told [64]. The application could be comparative in nature, which would be undertaken to examine a real-world situation using AsM and CSG, jointly and separately, to provide a rich picture and context to the articulated potential utility of CSG in AsM.

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