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Appreciative Methods Applied to the Assessment of Complex Systems

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Appreciate Inquiry and Social Complexity

Appreciative Inquiry

- Appreciative Inquiry Methods focus on participants/stakeholders, environment, authority, relationships (including the power relationships between stakeholders) and learning as a way to understand the complexity in a system and its interactions.

- Appreciative Inquiry (Cooperrider, 2003) is a transformational change methodology which leverages understanding from the disciplines of organizational behavior and the sciences of sociology and psychology (Stratton-Berkessel, 2018).
  - Social and organizational systems are complex, and as such Appreciative Inquiry is based on methods used to understand these complex systems. Thus, Appreciative Inquiry provides an excellent approach to begin a more in depth study of complex systems.
  - Appreciative Inquiry involves the art and practice of asking questions that strengthen the capacity to apprehend, anticipate and heighten positive potential. It seeks to identify and build on the knowledge of what has already been proven to work, when this knowledge is spread across many diverse stakeholders. (Cooperrider and MacQuaid, 2012).

Appreciative Inquiry

Problem-Solving Focus	Appreciative Inquiry Focus
Identification of problems	Identifying what is known and unknown, risks and opportunities
Analysis of possible causes	Assessing distinguishing characteristics of complexity; identifying areas to focus on
Analysis of possible solutions	Identifying strategies which have been useful with comparable complexity in other systems/situations
Implementation	Trying promising strategies
V & V	Noticing effects
Iteration	Refining our understanding of which areas of complexity to focus on
Basic assumption: Complexity presents problems to be solved	Basic assumption: Complexity offers a mystery to be explored

Social Complexity and Physical Complexity

- Groups of individuals working on complex physical systems may themselves be considered complex systems, yet to date it appears that attention given to the language of complexity focused on physical and logical systems may be a factor holding groups back from greater effectiveness in managing social risks they face directly and indirectly in their work.
- A broader understanding of the social complexity involved in the development and application of various systems is an important factor in system complexity. This understanding helps to discern the variations of complexity for a given system and context.
- The system context (i.e., the social environment) brings in various social aspects including government and organizational policy and law, budgetary constraints, schedule, organizational culture, environmental impact, etc. (Watson, 2018)

Distinguishing Characteristics of Complexity

Context

- First Step in Appreciative Inquiry involves identifying what is known and unknown, risks and opportunities

- Complex systems must be considered in their full context (i.e., mission context or statement of the problem to which the system provides the solution) including both the developmental and operational environments. This includes both the natural environment and the social environment in which the complex system is developed and operated.

- Boundaries and controls are sometimes employed to contain complex responses and can at times mask some characteristics of complexity within the system.

- The nature of system complexity can be either subjective (based on the limits of understanding of an individual or social structure) or objective (based on the characteristics of the system itself or its environmental interactions).

14 Distinguishing Characteristics of Complexity

Characteristic	Definition
Diversity	The structural, behavior, and system state varieties that characterize a system and/or its environments.
Connectivity	The connection of the system between its functions and the environment. This connectivity is characterized by the number of nodes, diversity of node types, number of links, and diversity in link characteristics. Complex systems have multiple layers of connections within the system structure. Discontinuities (breaks in a pattern of connectivity at one or more layers) are often indications of complex system connectivity. Simple and some complicated systems may be characterized by simpler structures such as hierarchies.
Interactivity	The behavior stimulus and response between different parts of a system and the system with its environment. Complex systems have many diverse sources of stimulus and diverse types of responses. The correlation between stimulus and response can be both direct and indirect (perhaps separated by many layers of system connectivity). The types of stimuli and responses vary greatly. The levels of stimuli and responses can range from very subtle to very pronounced. The timeframe for system responses can vary hugely.
Adaptability	Complex systems proactively and/or reactively change function, relationships, and behavior to balance changes in environment and application to achieve system goals.
Multiscale	Behavior, Relationships, and Structure exist on many scales, are ambiguously coupled across multiple scales, and are not reducible to only one level.
Multi-perspective	Multiple perspectives, some of which are orthogonal, are required to comprehend the complex system.
Behavior	Complex system behavior cannot be described fully as a response system. Complex system behavior includes nonlinearities. Optimizing system behavior cannot often be done focusing on properties solely within the system.
Dynamics	Complex systems may have equilibrium states or may have no equilibrium state. Complex system dynamics have multiple scales or loops. Complex systems can stay within the dynamical system or generate new system states or state transitions due to internal system changes, external environment changes, or both. Correlation of changes in complex systems to events or conditions in the system dynamics may be ambiguous.

14 Distinguishing Characteristics of Complexity

Characteristic	Definition
Representation	Representations of complex systems can be difficult to properly construct with any depth. It is often impossible to predict future configurations, structures, or behaviors of a complex system, given finite resources. Causal & influence networks create a challenge in developing 'requisite' conceptual models within these time and information resource constraints.
Evolution	Changes over time in complex system states and structures (physical and behavioral) can result from various causes. Complex system states and structures are likely to change as a result of interactions within the complex system, with the environment, or in application. A complex system can have disequilibrium (i.e., non-steady) states and continue to function. Complex system states and structures can change in an unplanned manner and can be difficult to discern as they occur. The changes in the states and structure of a complex system are a natural function of (is often present in) the complex system dynamics. Changes can occur without centralized control, due to localized responses to external and/or internal influences.
System Emergence (general)	Features/behavior associated with the holistic system that are more than aggregations of component properties.
Unexpected Emergence (Complex)	Emergent properties of the holistic system unexpected (whether predictable or unpredictable) in the system functionality/response. Unpredictable given finite resources. Behavior not describable as a response system.
Disproportionate Effects	Details seen at the fine scales can influence largescale behavior. Small scale modifications can result in radical changes of behavior. Scale can be in terms of magnitude of effect or aggregate amount of change. Weak ties can have disproportionate effects.
Indeterminate boundaries	Complex system boundaries are intricately woven with their environment and other interacting systems. Their boundaries can be non-deterministic. The boundary cannot be distinguished based solely on processes inside the system.
Contextual Influences	All systems reside in natural and social environments and relate to these. In the relationship between the system and the natural and social environments there can be complexity. This complex interaction depends on the social application of the system. Social systems often strive to achieve multiple, sometimes incompatible, objectives with the application of the same system.

Managing Complexity

Managing Complexity

- Results from the analysis of possible solutions as defined by Appreciative Inquiry
- Managing complexity first requires identifying the complexity of a system.
- The Multi-perspective of a complex system can make the complexity appear in different ways, and may even mask the complexity.
  - There are various ways a system and its context may appear complex: physical, logical, social interaction, social application, environmental interaction.

Managing Complexity

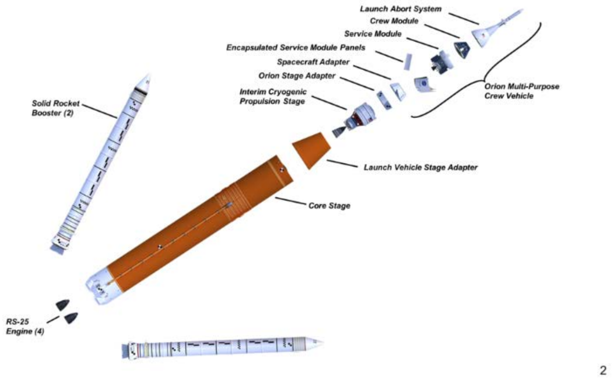
- Complex systems need balance rather than optimization. The whole is often sub-optimized when a part is optimized, or an optimized system can become rigid and cannot cope with changing circumstances and needs.
- Tension is common in complex systems. Tension between large and small, distributed and central, agile and planned, calls for perpetual seeking of balance.
- Complexity can be bounded within a simpler structure. E.g., biological cells are internally complex and yet a single cell is a simple structure externally.
- Architecture is defined in the INCOSE Systems Engineering Handbook as “the fundamental concept or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution.” (INCOSE 2010) The characterization of a system architecture in terms of some coordinated collection of subsidiary design elements (e.g., responsible ‘trades' for specific design elements) can be a major step toward organizing and managing complexity. Implicit in successfully navigating this task is mutual appreciation between responsible trades regarding their respective contributions and interactions to the evolving system(s).
- Social-Political Complexity. All systems reside in natural and social environments and inherently relate to these. In the relationship between the engineered system and the natural and social environments there can be complex interactions inducing pressures on socio-political and governance structures. This level of interaction often depends on specific and potential applications (uses) of the given system. Social systems often strive to achieve multiple, sometimes incompatible, objectives engendering risks and opportunities for the coevolution of systems services and value to society. Better understanding these co-evolutionary processes may prove useful to engineering organizations.

Complex System Exemplars

Complex System Exemplars

- Army Pot Helmet: The Army Steel Pot Helmet (Figure 1) is a simple steel helmet that included a shell, liner, strap, and cover. In application, the helmet had many more uses that were valuable to the soldier than just protecting from bullets and explosive fragments. Functions included head protection, identification, seating, fluid and solid containment, and heating (when used to prepare meals). The helmet could be used as a seat, a shovel, a wash and shave basin, a pot for cooking, and anything else the innovative soldier could image. (New York Times 1982, Webster, 2017)

- Launch Vehicle: Launch vehicles are very large physical systems whose development requires very large and geographically distributed efforts (operations teams, manufacturing, engineering organizations). Launch Vehicles are a complicated assemblies of physical parts in a static state as illustrated in Figure 2. In operation, they are a complex interaction of thermodynamic fluids, software, and electrical systems. Launch vehicles are not complex adaptive systems in the current state of the art. The addition of artificial intelligence systems in the current state of the art. The addition of artificial intelligence responses to responses to in-flight conditions would transform them into complex adaptive systems.



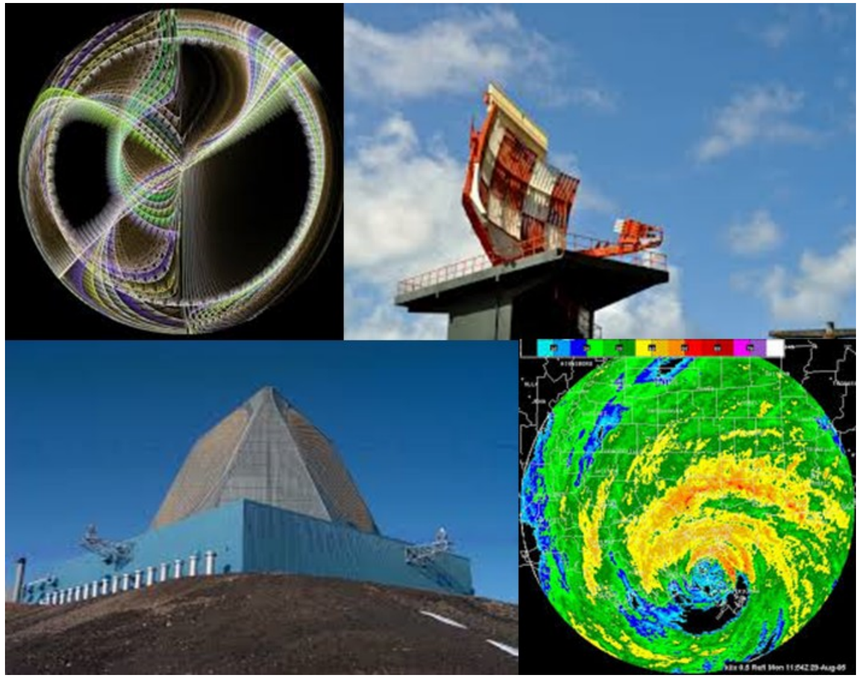
Complex System Exemplars

- Bullet Train (Shinkansen).
  - This is a nationwide transportation system in Japan and international catalyst interacting at many levels of hierarchy with multiple business, technical, social, cultural, political groups and organizations. (Straszak, 1981; Okada, 1994; Endo, 2003; Okamura, 2005; Tomii, 2010; Smith, R. A., 2014; Yokoshima, 2017; Asano, 2017) It has a robust and resilient architecture for reliable inter-city passenger transport. (Endo, 2003; Shimamura and Yamamura, 2006; Uda, 2010; Kato and Shinohara, 2013; Smith, R. A., 2014) It is heavily dependent upon minute to minute managerial competence due to its one-track paradigm. (Shimuzu, 2002; Kawasaki, 2011; Mochizuki, 2011; Tomii, 2010) The individual cars of the Shinkansen are complicated systems, yet the whole aggregated train is complex. Figure 3 shows various engine configurations used for the train. The Shinkansen system illustrates how aggregation of subsystems and confounding factors can both elevate the complexity of the system.

- Artificial Intelligence Image Collection Manager
  - A collection manager is a software system that assists experienced human operators in effective use of image collection assets through the generation of collection plans and tasking commands for a constellation of imaging devices that usually include satellites and may include airborne assets. Some constellations may include a range of earth based assets as well. The collection planning capability includes complexity in a number of dimensions including environment, social context and the interplay among elements of an evolving System of Systems.
  - Recently, scientists and engineers have begun to apply Artificial Intelligence and Machine Learning (AI/ML) to realize complex adaptive software systems that identify the best opportunities to collect requested imagery for unique mission needs within the confines of policy and law, environmental conditions and the capabilities of the vehicles and instruments available. Berger (Berger, 2016) describes the problem addressed by this system as “the process of converting intelligence-related information requirements into collection requirements, establishing priorities, tasking or coordination with appropriate collection sources or agencies, monitoring results, and re-tasking, as required”.
  - In most current deployed systems, this process is managed by a human, augmented by rules based automation. In the case of an AI/ML version of this capability, the system learns based on collection success over time and develops additional rules and algorithms to develop more effective collection schedules. More traditional implementations of collection management systems may be considered complicated or complex systems while AI driven implementations are complex adaptive systems.

Complex System Exemplars

- Radar:
  - A system which bounces radio waves off of targets to determine various characteristics of the target, usually including position, size and velocity. Analysis of radar echoes can use many techniques, including fractal analysis, which classifies shapes seen by the complexity of their geometrical form (Azzaz, 2017 and Cherouat, 2008). Practitioners of radar design, and developers of tools to support simulation and modeling of radar components and environments perceive radar design to be complex. For example, the MathWorks website says: “Radar system design, simulation, and analysis is complex because the design space spans the digital, analog, and RF domains. These domains extend across the complete signal chain, from the antenna array, to radar signal processing algorithms, to data processing and control. The resulting system level complexity drives the need for modeling and simulation at all stages of the development cycle.” (Mathworks, 2018)
  - The environment that radar has to contend with also can be complex, since rain, fog, plant matter and electromagnetic energy generated by other radars can interfere with a given radar’s ability to detect signals; also noise comes from sources ranging from the radar’s own transmitter, to energy from the earth’s atmosphere and the earth itself, to galactic noise from the cosmos. There are many choices, with associated trade-offs, in radar design. Examples of choices include: (1) power level (higher power can yield higher signal-to-noise ratios, and thus better performance, but also create more interference for other systems, and be more detectable (for systems in which the user does not want an enemy to know they are using radar); (2) wavelength (a higher frequency – shorter wavelength -- yields better tracking performance, but a lower frequency means less power needs to be used, and the receiver can be smaller); and (3) receiving aperture size (a bigger aperture means better performance for a surveillance radar).
  - Radar is starting to use adaptive approaches, such as a “cognitive radar system” based on the fully adaptive radar framework for cognition (Smith, et al, 2016) For example, pulse repetition frequency and number of pulses can be adjusted dynamically to maintain radar tracking performance (Butterfield, et al, 2016). The key concept is that radar system performance can be enhanced through a continuous and coordinated feedback between the transmitter and receiver that implies a dynamic adaptation of the sensor’s algorithms to the operational context and environmental replies.



Complexity Assessment

Complexity Assessment Factors

- Integrating perspective.
  - The integrating perspective of any system allows the system to be more clearly understood. If the integrating relationship is known, then the system can be understood, and may even appear to be less complex from this perspective. The integrating perspective of a complex system is not intuitively obvious to the casual observer.
  - Intentionally engineered complex systems are constructed in such a way as to provide a direct view of the integrating nature of the system sometime presenting a more informative view of the system. This perspective enhances our understanding of the system and how to deal with this complexity.
  - The integrating perspective enables the construction of models to aid in the understanding of the system and its complexity. Integrating perspectives reduce resource demand to be able to predict system behavior.
  - Malleability is a property that allows the complex system to be deconstructed and/or reconstituted around the integrating perspective. Complex systems are malleable around their integration perspectives.
  - Complex system variables can be opaque. These complex system variables are difficult to identify and predict apart from the system integrating perspective.
- Confounding Factors.
  - Even with a very simple system, there can be complexity in the environment, in the interactions between stakeholders, and/or other factors. These confounding factors can introduce complexity even when the system under consideration is not, in and of itself, complex.
  - In dealing with complexity, it is helpful to identify the specific characteristics, and/or confounding factors, which are the major sources of complexity. Once these are understood, discussions with stakeholders and specific techniques and tools to deal with the complexity can be chosen to better address the complexity and the challenges it introduces into a system development, operation or modification effort.

Complexity Assessment

- Assessment
  - The following tables compare the different examples on each of the distinguishing characteristics of complexity described above. In doing this comparison, we use Appreciative Inquiry to examine both the complexity of the system itself, and, when applicable, complexity caused by what we call “confounding factors”.
  - We have rated each example system characteristic on a scale of 1 to 10, where 1 = simple, 5 is complicated, and 10 is highly complex. When a confounding factor is present, we have also rated the level of complexity it introduces. The purpose of these ratings is to highlight the distinguishing characteristics of each system which are most complex.

Complex Exemplars Assessment

Example System => Characteristic:	Army Pot Helmet	Bullet Train	Radar
Bottom line: Simple, Complicated or Complex?	Simple	Complex	Complicated (with dynamic artificial intelligence algorithms, may be complex adaptive)
Diversity	3 Minimal	8 Stable goals for system wide performance are difficult to attain and maintain due to constant pressures for increased speed, ridership, social embrace, and profitability. Over years of operation the system accumulates an increasing variety of rolling stock, component inventory, operating procedures, and levels of regional capacity.	7 Moderate (many different engineering disciplines needed, leading to high subjective complexity)
Connectivity.	2 Minimal (head interface)	8 Ultimately, system connectivity is defined by inter-nodal relationships (e.g., riders moving from one place to another). These relationships are mediated by rider trust and the 'weighting' afforded by trusting populations. These populations are further coupled with events e.g. business schedules, seasonal activities, weather, economic cycles, etc	6 Moderate (may connect to other systems)
Interactivity	2 Minimal (adapt, don/doff, secure /release) 6 Confounding factor: Uses for other purposes (such as cooking)	9 Numerous interactions between the system and its environment: various experiential dimensions (e.g., cost, punctuality, comfort, quiet) and social embrace/ridership/profitability; various technical dimensions (e.g., aerodynamics and vibration, earthquakes and safety, weather and punctuality, rolling stock and performance, etc.)	6 Moderate (often interacts with other systems)

Complex Exemplars Assessment

Example System => Characteristic:	Army Pot Helmet	Bullet Train	Radar
Adaptability	2 Minimal (size, shell on/off, cover on/off)	8 In order to achieve overriding goals for system punctuality, the technical system must be extremely adaptable in responding to variability in weather conditions across geographical regions as well as multilevel (across temporal and spatial scales) scheduling logistics, anticipated ridership, etc.	6 Moderate
Multiscale	1 No	9 The technical system is a composite of elements that can be described at various scales: materials, components, unit assemblies (cars, engines, couplings, stations, tracks, region/prefecture, whole system, etc.). In addition the operating organization can be described at various levels of hierarchy (e.g., departments, lines, company, etc.)	8 Yes: particulate level affects performance, while higher-level choices such as waveforms and frequency have different dynamics; coverage is at a large scale.
Multi-perspective	1 No	9 Technical system states and events are routinely represented, referenced, and interpreted from multiple perspectives by different facets of the operating organization (mechanics, schedulers, service personnel, management, etc.), stakeholders (riders, residents, business, towns, cities, prefectures, regulators, journalists, countries, etc.), and others (disinterested humans and non-humans). Such perspectives routinely and generatively feed back into system states and events.	5 No (though may be used in a system -of-systems which is multi-perspective)

Complex Exemplars Assessment

Example System => Characteristic:	**Army Pot Helmet**	**Bullet Train**	**Radar**
Behavior (not describable as a response system)	1 No	9 At lower levels of assembly hierarchies (bogies, pantographs), behaviors can be well characterized. But given the diversity and unpredictability of the system at higher levels of aggregation, system control becomes increasingly subject to human intervention and certain inputs (e.g., energy flows, line loads) or outputs (e.g., trackside noise, sparking) may exhibit challenging or problematic behavior; such side effects can effectively limit important dimensions of system performance (profitability, market share) prompting system evolution (research and development).	3 No 10 If artificial-intelligence algorithms are used to dynamically alter characteristic of waveforms sent and receiving processing
Dynamics complex	1 No	5 While selected dynamics of the technical system may be reproducible in test facilities, in the field such simple results may not be conclusive. Consider, for example human response to noise, vibration, pitch, and yaw under variable track conditions. To the extent that changing conditions can be anticipated, adaptive responses can be designed and deployed.	4 Moderately
Representation difficult	1 No	8 Considering the variety of operational states achieved and/or maintained far from equilibrium by the technical system relative to e.g., specific environment, component operating and life-cycles, physical, technical, or economic conditions, a discrete enumeration of system states could prove un-representable. However, managerial and technical systems exhibit numerous representational features contributing to robustness and resilience of long term development: e.g. active tracking of commitments to physical infrastructure, research and development capability and performance measures considering large-scale/long-term effects, such as long term profitability and growth, technical performance competitive with air travel.	8 Representation complicated; interference and noise make response description less accurate

Complex Exemplars Assessment

Example System => Characteristic:	**Army Pot Helmet**	**Bullet Train**	**Radar**
Evolution	1 No	5 Day to day and year to year operational system evolves with experience and technology, through techno-social and organizational learning processes. Day to day and year to year operational system continuously generates novelty - although it is usually hidden or ignored/tolerated to a degree (e.g., within bounds of system-wide punctuality). Also see the entry on Representation.	3 No 10 (except when dynamic AI-based algorithms are used)
System Emergence not predictable behavior	1 No	8 Stable goals for system wide performance are difficult to attain and maintain due to constant pressures for increased speed, ridership, social embrace, and profitability. Over years of operation the system accumulates an increasing variety of rolling stock, component inventory, operating procedures, and levels of regional capacity.	5 No 10 (unless dynamic AI-based algorithms are used)
Disproportionate Effects	1 No	10 Local events or state changes at distant station pairs can produce system-wide effects. Also see above re small scale modifications. Due particularly to one-track logistics, small changes on the scale of minutes can produce extensive change in system configurations and system wide effects taking place over days and longer. Also see the entry on Unexpected Emergence	4 No Confounding factors: 9 Environmental changes, especially ones which are very rapid, can cause unanticipated performance problems

Complex Exemplars Assessment

Example System => Characteristic:	Army Pot Helmet	Bullet Train	Radar
Indeterminate Boundaries	1 Distinct Boundaries	10 Physical track corridors are determinate however the boundaries of interactions between the technical system and surrounding environment are fuzzy. Noise envelopes, ridership catchment, and line capacity are soft and always evolving. for example. Also, maximum speeds are opaque in the absence of extensive testing, standard development, and public feedback. This only partially accounts for other variables such as management and energy costs associated with schedule maintenance which are effectively unknown until they happen.	3 The boundaries between a radar system and the context in which it is operating are typically very clear.
Contextual Influences	5 In Application	10 Nationwide system (Japan) and international catalyst interacting at many levels of hierarchy with multiple business, technical, social, cultural, political groups and organizations. Managerial system exhibits numerous strategic features contributing to robustness and resilience of socio-political interactions: e.g. participation in regional, national, and international transportation standards and policy development.	

Complex Exemplars Assessment

Example System => Characteristic:	Launch Vehicle	Artificial Intelligence Scheduler
Bottom line: Simple, Complicated or Complex?	Complex	Complex Adaptive
Diversity	8 Constrained Diversity - The system design accounts for diversity in operation	5 The learning function of the scheduler is very diverse. Specific intent to make everything but the learning function as deterministic as possible. The majority of the system has constrained diversity typical of a software system that controls hardware in space.
Connectivity.	7 Intricate and Diverse Connectivity	6 The learning function of the scheduler has complex connectivity. The system has structural complexity typical of a software system that controls hardware in space.
Interactivity	8 Controlled Boundaries, not well predicted.	6 The scheduler is instructed to propose the most likely collection opportunities based on historical performance, which it assesses using learning algorithms The majority of the system has stimulus/response complexity typical of a software system that controls hardware in space.
Adaptability	6 Limited: Vehicles are designed to withstand changes and operations to stay within limited ranges. Advanced GN&C software is emerging that is adaptive and will increase the vehicle adaptability to trajectory and environmental perturbations.	8 Open adaptability within loose constraints. This system is designed and encouraged to adapt.

Complex Exemplars Assessment

Example System => Characteristic:	**Launch Vehicle**	**Artificial Intelligence Scheduler**
Multiscale	10 Yes: The system has several scales: rocket, stages, and engines. Each can be viewed as a separate system or a component system part of the larger whole.	7 Possible multiscale. The schedulers learning decisions may be based on conditions at multiple scales, but the precise rationale for the decisions is opaque.
Multi-perspective	9 Yes: There are several perspectives needed to understand the system as a whole: Physics (thermodynamic, mechanical, electrical, optical, atmospheric, etc.) Value (Economic), Policy, Law, multiple stakeholder classes with different values of the system.	7 The leaning scheduler itself has a single perspective, but its options are constrained by rules made from multiple perspectives.
Behavior (not describable as a response system)	9 Yes: The amount of information needed to understand system response through all flight phases is not currently obtainable. The models of things such as atmospheric conditions, space radiation environments, and thermal vacuum interactions are not accurate enough to fully describe the system behavior.	7 Difficult to describe. Scheduler learned decisions are opaque.
Dynamics complex	7 Yes: Monte Carlo is state of the art analysis for many aspects. Nonlinear response regimes are particularly not simple averages. Confounding factors: Natural / Induced Environments can induce highly dynamic behavior	7 Somewhat dynamic. Scheduler is intended to learn to deal with the interaction of multiple environmental constraints.
Representation	10 Yes: Disaggregated There is a great deal of unpredictability in the component systems, and their interactions. Most accidents stem from not understanding or predicting the system level response from some "simple" changes in a system or environmental parameter.	7 The learning algorithms are difficult to represent beyond fundamental equations and logic structures.

Complex Exemplars Assessment

Example System => Characteristic:	Launch Vehicle	Artificial Intelligence Scheduler
Evolution Confounding factors:	5 Somewhat: Rocket designs to evolve with time and technology. Shuttle was stated as a 30 year flying experiment. The shuttle never flew the same system configuration twice. There were always changes and upgrades. 10 Artificial Intelligence could lead to evolutionary characteristics in future systems.	8 Designed Evolution. The system changes its rules but not its functions.
System Emergence not predictable behavior	9 Somewhat: Novelty comes from the flight patterns and payloads placed in orbit. The space program continuously generates novelty. The rocket is part of this larger system and enables the novelty.	8 System is designed to learn based on results and emergent behavior in some fashion is expected. Unexpected Emergence in collection requests over time.
Disproportionate Effects	10 Yes: This is seen everyday in rocketry. A few temperature degrees change can cause < mm change in dimensions and cause the system to lose functionality. Small pressure changes can have large effects on propulsion efficiency. Rockets have very subtle relationships. Soft foam moving at Mach speeds can break strong reinforced carbon panels. There is no direct tie, yet the interaction is catastrophic.	8 Highly Disproportionate Effects. Learning decisions may create large shifts in behavior based on small changes in input.
Indeterminate Boundaries	8 Environments are highly indeterminate. Flow fields are indeterminate. Mechanical boundaries are well defined in nominal operation. Confounding factors: 9 Atmospheric environments are complex and difficult to predict for a given launch site and day of launch.	8 Environments and requests are highly indeterminate. Environmental boundaries are indeterminate and vary with local conditions. Requests vary widely.

Complex Exemplars Assessment

Example System => Characteristic:	**Launch Vehicle**	**Artificial Intelligence Scheduler**
Contextual Influences	10 The natural environment relationship is highly variable and difficult to predict. The social interactions between the large design teams (1000's) and the rocket design are large. There is significantly complexity in the social interactions of the design organization leading to vary different designs for similar problems. The designs are difficult to compare without the integrating context. The social value of the rocket is also subtle and difficult to measure. Value for commercial telecommunications satellites vs. intergalactic astronomy platforms is very different in both near term value and long term value. The value of these different applications (payloads) is not currently possible to quantify.	8 High impact. Law and policy of multiple nations and many mission requirements interact to constrain the system.

Complexity Assessment Results

- Systems can be viewed as complicated when only considering the assembly (aggregation) of components yet are very much complex in their dynamic operation.
  - This is an aspect of the multi-perspective characteristic and shows complexity can sometimes be hidden from the normally perceived view of the system.

- Complex systems are not complex in all of their characteristics.
  - The assessment shows that even complicated systems (i.e., radar systems) can have complex characteristics and that not all characteristics of a complex system may be complex.

- Complexity is not a simple yes or no attribute.
  - Complexity is based on multiple characteristics not all of which are likely to be complex for most systems.
  - Even a Complex Adaptive system only shows complexity in some of the characteristics (i.e., Artificial Intelligence Scheduler) of the system indicating the other characteristics have more of an effect on a systems complexity than the adaptability functions.

- Confounding factors are significant aspects in the complexity of a system.
  - These factors can elevate a system from complicated to complex in the systems application.
  - This elevation can be seen for the pot helmet where the application of a simple structural system is complicated and can lead to very complex results in the organizational system that utilizes it.
  - In addition, there are many other subdivisions of complexity that can emerge including managed/constrained complexity (where the complexity is hidden by physical control boundaries and hence “managed or constrained” to not be apparent), expected and unexpected emergence, aggregation, and physical environment interaction.

Complexity Assessment Results

- The assessment of these systems indicates that there are tiers of system complexity.
  - Systems can be a complicated assembly in a static sense, and a complex interaction of parts and physical phenomena in a dynamic sense.
  - A distinction can also be made between complex systems and complex adaptive systems as discussed above. Complex adaptive systems encompass capabilities to respond to their contexts in unexpected manners.
  - Artificial Intelligence can transform a complicated or complex system into a complex adaptive system by imbuing the system with adaptive responses to their social and physical environments.

System Complexity Tier	Characterized by
Complicated	Assembly of static parts
Complex	Interactions of dynamic operations
Complex Adaptive	Application of Artificial Intelligence determining system responses

Complexity Assessment Conclusion

- Complexity and Engineering are not antithetical .
  - On the contrary, it is important to recognize that complexity can (and demonstrably does) spawn novel engineering communities that coevolve with their work products and also that it is essential that engineering organizations avoid fixating on singular methods or approaches to complex design problems by failing to appreciate the multiplicity of considerations that may be salient to problems at hand. Complexity can offer exercise to the imagination, to say the least. Future efforts toward discovering useful guidance may benefit from considering the 'appreciative tendencies' of organizations responsible for and responsive to successful complex system design and implementation. Summary
  - It is essential to notice that engineered systems and engineering organizations (including directly/indirectly interested and disinterested agents) constitute complete systems operating 'far from equilibrium' and that complexity, managed appreciatively, need not be an insurmountable barrier to the effective realization of engineering value.

- Described characteristics which can be used to identify complexity in a system, and the additional confounding factors (i.e., social and physical environmental interactions) which can elevate complexity of complicated systems.

- Systems can have various tiers of complexity ranging from static to dynamic to adaptive complexity.

- The evaluations of system complexity show that complexity is not a simple yes or no assessment, but there are several different characteristics of a system which may be complex. Not all of these distinguishing characteristics of the system need to be complex in order for the system to be complex.

Complexity Assessment Conclusion

- “Complexity engineering has still not been established as a proper engineering domain. Research remains scattered and focused on specific examples, which is the reason why most methodologies are not generally applicable. We would like to encourage other researchers to make efforts in complexity engineering, and to coordinate their research with peers. A general framework for complexity engineering should be created, linking existing and new methods with each other, giving receipts for how to approach which type of problem. Complexity engineering requires particular attention concerning the following issues: theory, universal principles, implementation substrates, designing, programming and controlling methodologies as well as collecting and sharing of experience.” (Frei and Di Marzo, 2011)

- This paper indicates several topics of future research.
  - The concept of Complexity Tiers observed in the assessment of the examples is a fruitful concept that may help explain the sometimes divergent opinions on what is or is not complex.
  - In addition, there are subcategories of complexity indicated in the assessment of the systems in the paper which should be further defined, including ideas such as managed complexity, constrained complexity, expected or unexpected emergence, social application complexity, operational complexity, etc. Some of these topics may be related and research is needed to define these subcategories more clearly and what constitutes a complicated or complex system when there is a large mix of complicated and complex system characteristics.
  - Also, research into the benefits which have been obtained from different systems engineering techniques when faced with complexity of a system or its confounding factors on each individual characteristic may yield useful guidance for dealing with complexity.

2019
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