COMPLEXITY LITERATURE REVIEW

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"The whole is more than the sum of the parts"--Aristotle

"We are not arguing that management science or systems thinking have no use at all or that managers should abandon rules and systems. On the contrary, we are pointing to the need to pay careful attention to how people go on with each other in their day-to-day organizational lives as they use the rules and systems they have designed, despite the drawbacks of those systems; namely, that they cannot cope with all eventualities and they cannot keep up with the pace of change. …We are arguing, however that [systems thinkers'] attempts to deal with the problems do not really succeed because they try to deal with the problems on the basis of systems thinking itself. The problems arise because of the theory of causality underlying systems thinking. ***No attempt to deal with the problems can succeed while this theory of causality remains the exclusive focus*** *(emphasis mine)."(Stacey)*

This paper represents background material for the PNSR Working Groups as we work to accommodate leading ideas from across multiple disciplines to craft problem statements and recommended solutions. The paper is a companion piece to the Annotated Bibliography on Complexity, also developed by the KM Working Group. Several cross-disciplines have come up in conversations, and the field of complexity may be the most salient at this stage of our research. What follows represents more of a path or shortcut than a comprehensive overview regarding decades of complexity thinking as well as a near-century of organizational science and 60 years of systems thinking.

As with all our work, the intent is to address leading voices in the disciplines, and focus on implications for national security. While this is useful as a focus in many areas, the confusion and controversy around complexity demands a more first-order approach, at least for this paper. Hence the notion of a Primer. Not intended as comprehensive, but intended to convey at least an introduction to this exciting field (or field of fields), so that we may continue with a shared understanding of implications and limitations that present themselves.

The paper provides an introduction to the field, a summary of key terms and concepts, and then discusses some important aspects of human interaction in systems. We conclude with a discussion of the implications for National Security planning and a summary of the key points of the literature.

Introduction

Complexity Theory encompasses multiple areas of study including Chaos Theory (introduced to the general public in the movie *Jurassic Park*), Complex Adaptive Systems, Agent behavior, non-equilibrium, emergent behavior, and multiple others. All of these are attempting to describe or in some cases quantify environments that do not fit traditional cause-and effect thinking. Traditional systems thinking seeks to determine the root cause of a certain result and quantify the variations in the result based on changes to that root cause. In other words A causes B which might then cause C. This type of system is called linear. When linear thinking is applied to more involved systems the effort, prior to complexity theory, was to create models with additional variables, sometimes weighting them based on probability of occurrence or possibly on estimated impact. The resultant output from such models usually included a range of values and the decision-maker was left to weight these outcomes based on their own gut or some other external set of models. Again, the notion was that with enough data and enough computer cycles the Pareto-optimal solution would be calculated. A great deal of modeling, simulation, and super-computer effort is expended in trying to predict the weather. However, even small changes in inputs to our largest models yield enormous variances in outcomes. A small change can turn a sunny day in Texas to a stormy day in China.

Complexity theory models the world in a different manner. It takes as a root premise that certain systems are, by their very nature, non-linear, that they change their behaviors based on their starting points and the random events that might ensue. That the individual actors within the system change their behaviors in some ways that might be predicted but also in manners that can not be envisioned. From these actors might emerge new behaviors that could not be predicted. While specific outcomes can not be predicted, certain things might be anticipated. The difference is essential to the understanding of complex systems. Linear models are generally developed with the goal of predicting the future. Complex systems can help us anticipate that certain classes of events might take place. For example, a linear system might be built to predict which toy would be the "hot" Christmas seller. Taking the results of this a retailer might pre-order and stockpile a large number of that toy and hope that the model was correct. A complexity theory view of this would yield us a result that one of several toys are likely to be the hot seller, in fact several might. A retailer might then respond by establishing flexible purchasing contracts with the manufacturers, dynamic warehousing, and adaptive marketing materials.

Managing apparently simple situations using the two paradigms, linear thinking, and complexity thinking, can yield dramatically different results. The classic example is a children's birthday party. If we took today's National Security system's linear approach we might plan a detailed schedule of the event. We would welcome the children to the party and in-brief them on the plan. We would let them know the desired outcomes, expected behaviors and inform them that this will result in high values of fun for all. We would then escort them to activity one. Almost immediately this plan would fall apart with great confusion on the part of the planners and a great deal of complaining on the part of the children. In contrast, a parent, having a more granular understanding of what can and can not be controlled, would provide a space for the children to play and interact, provide some toys or games to focus their energies (attractors) and then inject themselves to discourage bad behaviors or reward positive ones. At certain points in the event larger changes would be introduced (cake cutting and eating, present opening) and in the end the children would all go home well sugared and happy.

Wal-Mart is one company that has embraced the complexity model in managing its operations.

A New Exemplar – How Wal-Mart Works

"We have an infrastructure that allows us to react" – H. Lee Scott, Jr., CEO, Wal-Mart

"At 8 a.m. on Wednesday, as New Orleans filled with water, Wal-Mart chief executive H. Lee Scott Jr. called an emergency meeting of his top lieutenants and warned them he did not want a 'measured response' to the hurricane (Barbaro and Gillis)." The response from Wal-Mart to the devastation after Hurricane Katrina hit New Orleans and the Gulf Coast remains an object lesson in effective disaster response. One Parish official quoted in the Post article told a news program: "the American government would have responded like Wal-Mart has responded, we wouldn't be in this crisis." Within days, Wal-Mart provided $20 million in cash donations, 1,500 truckloads of free merchandise, and food for 100,000 meals. In addition, when looting hit the local Wal-Mart stores, corporate officials decided to do nothing to stop the looting or recover the endangered merchandise.

How did Wal-Mart succeed in such dire circumstances?

- **Supply chain optimization**. Wal-Mart has an infrastructure that, as per its CEO, positions it well to react. Wal-Mart literally changed the internal organization and processes of one of its chief suppliers (Grean). Proctor & Gamble (P&G) had been a organized regionally, and relied on Wal-Mart and other retailers to inform them of inventory levels on a regular basis. Wal-Mart felt this was insufficient and inefficient for their growth goals, and the resulting agreements led to an integration of information technologies and processes to an unprecedented level. When a P&G product is scanned in any Wal-Mart store checkout line, that information is immediately available to the supplier. P&G monitors inventory levels, and delivers goods using a just-in-time inventory system. In addition, P&G – using the aggregate of these data – can monitor trends and position Wal-Mart stocks accordingly. By studying these trends across the Southeast US, among other things, Wal-Mart knows that hurricane victims increase their consumption of strawberry Pop-Tarts and the mechanisms in place position it well to respond to changing eating patterns.
- **Command center operations.** Wal-Mart has a 24-hour command center to monitor events that may affect their business. *"Before Katrina, Wal-Mart had built what it calls an emergency operations center designed to allow--even force--employees from different departments to work in close proximity during a disaster. Katrina put it to the test. By having people work in the operations center, it let people from multiple parts of the company make decisions and set priorities on what tasks and systems were most important. Wal-Mart also utilized a dashboard system developed for the operations*

center that gives the company the visibility it lacked--showing each store's damage, whether employees were at risk or injured, and if the store has communications platforms running and whether they're running on landlines or satellite systems or utility or generator power (Sullivan).” As a result, the distribution center in Brookhaven, Miss had 45 trucks of goods loaded before Katrina made landfall. Additionally, Wal-Mart arranged for a special line at a nearby gas station to ensure its employees would be able to make it in to work. (Barbaro & Gillis)

- **Agile Reponse.** The decisions made reflected the diversity of opinions (as evidenced by the local staff in command centers) and an awareness of emerging patterns in the evolving situation. From deciding not to intervene when faced with looting, to launching a web site where affected residents could post messages to friends and family, Wal-Mart demonstrated an agile decision and execution process that allowed it to adapt its response based on the situation – rather than solely upon “lessons learned” from previous hurricanes. As such, the unprecedented scope of the disaster did not derail Wal-Mart relief efforts.

This is not to say that the national security system should mimic the Wal-Mart example, but this company is an excellent example of how a large disparate organization can function in complex situations by positioning its infrastructure (and embedding knowledge through the delivery system), monitoring events, and allowing for agile and creative decisions.

KEY Concepts and Terms:

There are many branches of complexity theory but most will at some point use one or more of the key terms described below:

<u>Agents:</u> Agents are the actors within a system. They perceive their surroundings, develop a schema to interpret what they are perceiving and then make decisions based on their own criteria.

<u>Adaptive:</u> Complex systems are adaptive in that the Agents will modify their behaviors based on the circumstances in which they find themselves. What the specific adaptation will be might not be knowable in advance.

<u>Emergent Behavior:</u> Emergent behaviors are new unanticipated patterns of action that are demonstrated by Agents. They are adaptations to the environment.

<u>Self-Organization:</u> Actors within a complex system self-organize, that is, they will form new structures and connections, networks, and systems to meet their needs should their existing structure prove overly cumbersome or ineffective.

<u>Equilibrium/non-Equilibrium:</u> Complex systems, in many cases, will never achieve equilibrium. There might not be a steady-state or a resting state. They might be in flux constantly and no manner of influence will drive them to a state of no change.

Diversity: Complexity theory recognizes that the Agents of a system are themselves diverse both in terms of their behaviors but also in their perceptions of their situation. This diversity of viewpoints and behavior interact and modify each other.

Schema: Schema are the mental models that an Agent has of their situation. It is how they interpret their environment and ultimately the basis for their future decision making.

So…with these building blocks we can now define a Complex Adaptive System (CAS), the overarching term-of-art: Dooley, et al define it as:

> The basic elements of a CAS are agents. Agents are semi-autonomous units that seek to maximize their fitness by evolving over time. Agents scan their environment and develop schema. Schema are mental templates that define how reality is interpreted and what are appropriate response for a given stimuli. These schema are often evolved from smaller, more basic schema. These schema are rational bounded: they are potentially indeterminate because of incomplete and/or biased information; and they differ across agents. Within an agent, schema exist in multitudes and compete for survival via a selection-enactment-retention process. When an observation does not match what is expected, an agents can take action in order to adapt the observation to fit an existing schema. An agent can also purposefully alter schema in order to better fit the observation. Schema can change through random or purposeful mutation, and/or combination with other schema. When schema change it generally has the effect of making the agent more robust (it can perform in light of increasing variation or variety), more reliable (it can perform more predictably), or more capable in terms of its requisite variety (in can adapt to a wider range of conditions).
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> The fitness of the agent is a complex aggregate of many factors, both local and global. Unfit agents are more likely to instigate schema change. Optimization of local fitness allows differentiation and novelty/diversity;global optimization of fitness enhances the CAS coherence as a system and induces long term memory.
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> Schema define how a given agent interacts with other agents surrounding it. Actions between agents involve the exchange of information and/or resources. These flows may be nonlinear. Information and resources can undergo multiplier effects based on the nature of interconnectedness in the system. Agent tags help identify what other agents are capable of transaction with a given agent; tags also facilitate the formation of aggregates, or meta-agents. Meta-agents help distribute and decentralize functionality, allowing diversity to thrive and specialization to occur. Agents or meta-agents also exist outside the boundaries of the CAS, and schema also determine the rules of interaction concerning how information and resources flow externally.

Implications

The implications for the insights from complexity are profound. Systems scientists, organizational theorists, and business leaders are beginning to work in a world where control can be an illusion and adaptation preferred. The characteristics of an organization that focuses on the latter differ significantly from the former.[1]

Snowden and Boone provide organizational leadership attributes for complex systems that are illuminating concerning the desirable system attributes for our national security system (quotes from Snowden 2007):

1. Open up the discussion. In their piece, Snowden and Boone were focused on the use of Large Group and other methods to encourage broad conversation across diverse voices. As applied to national security systems, this appears to reinforce the finding in the DoD Information Sharing Strategy, released in 2007: "Though it is important that the DoD continue to proactively plan for information sharing with anticipated partners and events, it is also critical to prepare for unanticipated partners and events. To accomplish information sharing in diverse and disadvantaged situations, the DoD shall enact and implement adaptive policies, guidance, practices, protections, and technologies."
2. Set barriers. Barriers limit or delineate behavior. The analog for our purposes would be the attribute "selective in behavior." Sample actions here include the establishment of roles and responsibilities, and the protocols for prioritization, as the system cannot act equally on all that it perceives.
3. Stimulate attractors. "Attractors are phenomena that arise when small stimuli and probes (whether from leaders or others) resonate with people. As attractors gain momentum, they provide structure and coherence."
4. Encourage dissent and diversity. "Dissent and formal debate are valuable communication assets in complex contexts because they encourage the emergence of well-forged patterns and ideas."
5. Monitor starting conditions and monitor for emergence. "Because outcomes are unpredictable in a complex context, leaders need to focus on creating an environment from which good things can emerge, rather than trying to bring about predetermined results and possibly missing opportunities that arise unexpectedly."

Desired Attributes for National Security System – Derived from Complexity Research

Must have ability to monitor for, and detect, weak signals (Nonlinear characteristics for CAS). Because small events or "data anomalies" can reverberate in complex systems and produce nonlinear effects (results far beyond their perceived organic ability), the national security system must be geared to make sense of "minor events" in case they minor becomes strategic. Rosenau (1996) details how this principle "enables us to grasp how an accidental

[1] This is not to say that linear processes have been overtaken by complexity, the findings of complexity within organizational management literature adds to our understanding of organizations, but linear management remains appropriate for production systems, etc.

drowning in Hong Kong intensified demonstrations against China, how the opening of a tunnel in Jerusalem could give rise to a major conflagration…how an 'October surprise' might impact strongly on an American presidential election…" One could add easily to this list (assassination of an Archduke, etc.). The Singapore initiative is illustrative here (Rapid Analysis and Horizon Scanning) (Quiggin 2007). Understanding that the system cannot act equally on all that it perceives, this characteristic means in order to determine what to act on, a system needs a clear and responsive method of making sense of the environment and priorities.

- In complex systems, initial conditions matter. Small events can generate massively significant consequences. Before September 11, 2001, parts of the intelligence community knew that Al Qaeda members were engaging in flight-training activity in several US cities. The community did not put those signals together. **The national security intelligence function must have the ability to detect weak signals** that portend potentially disruptive strategic effects. That said, it is unwise to assume predictive abilities or that we can "connect the dots."[2] The best we can do is monitor patterns and detect weak signals that may indicate seemingly minor events that may lead to significant consequences. Key finding here: *complex systems are not predictable*. Some believe they are deterministic in some fashion – as chaos systems are deterministic but still unpredictable - but coherence is retrospective throughout the literature. Given the locality of complex systems, resources should be devoted to understanding the attractors and modulators that influence local interactions in interesting areas of the world (Tibetan response to 2008 Olympics, Zimbabwe population reaction to election results, Balkan mood following Kosovo independence, etc.).

- Control is not a property of a complex social system. But *influence* is. Because complexity emerges from the unpredictable interaction of multiple actors, national security policy success depends as much on continuously shaping networks as attempting to control them. Incorporating multiple perspectives is critical to effectively influencing a dynamically emerging system. As appropriate, the national security system must allow **decentralized policy execution and semi-autonomous decision-making**.

- *Emergence* is a second order property of a complex system. It refers to the "whole" that is greater than the sum of the system's parts. The national security system must be able to identify and respond to the emergent identity shifts and organizational structures that can characterize international and other systemic behavior. This means the structure and roles of the national security system must be sufficiently flexible to anticipate and

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[2] The fact is that the future will always have sufficient uncertainty such that attempts to "connect the dots" *a priori* will meet with random success at best. One way to illustrate this is to consider a simple matrix of four "dots" that need to be connected. In this example, there are six different ways in which the dots can be linked, and a total of 64 possible patterns (outcomes) based on the interaction among the dots. This appears manageable, but the problem quickly grows asymptotically. With a population of 10 "dots" the number of possible linkages is 45 – but the number of possible outcomes is 3.47 ***trillion***. (Formulae: Links (L)=N(N-1)/2 and Patterns (P)= 2^L.)

respond to emergent challenges. **The national security system must be able to engage issues at the level of the "whole," in a way that may transcend component agency interests**.

- The national security system must blend the *normative* with the *natural*. Complex social systems do not attain final equilibrium. The **national security system is more an ecology than a machine**. It changes through both intention and circumstance. The strategic perspectives appropriate for addressing gaps between a normative ideal and empirical reality can be supplemented by a naturalistic approach. The naturalistic approach sees the current state of a system not just as a problem to be solved but also as an opportunity to be realized.

In discussing complex adaptive systems (CAS), the literature review results in the following list of CAS attributes, by author, below. The exclusion of properties in a single column should not be taken to mean that the author disputes that property – we represent in this table the properties/attributes that were *emphasized* in the subject works:[3]

[3] There are no perceived values across the cell rows in this table, this is a first-order compilation of system attributes by author. We have not here applied any taxonomy over the collection of attributes.

Firestone & McElroy	Moffat	Snowden	Gell-Mann	Holland	Tsoukos	Waldrop	Rosenau	Stacey
Identity	Non-equilibrium order	Operate far from equilibrium	Highly sensitive to starting conditions	Aggregation	Non-linear	Systems are simultaneously pulled both towards and away from equilibrium	Small events can throw a system into disequilibrium	Identity is not persistent, can be transformed
Diversity	Collectivist dynamics	Principle of locality	Agents scan and develop schema, which define interaction and are subject to change	Tagging	Fractal	Principle of locality	Co-evolution	Coherence emerges through agent interaction
Adaptive	Adaptation	Constant adaptation		Flows	Exhibit recursive symmetries	Emergence	Adaptation	Evolving
Distributed knowledge processing	De-centralized control	Highly sensitive to starting conditions		Nonlinearity	Sensitive to initial conditions		Sensitivity to initial conditions	
Extensive agent interaction	Nonlinear interaction	Emergence		Diversity	Possess many feedback loops		Emergence	
Self-organization	Self-organization	Self-organization		Internal models			Self-organization	Self-organizing
Rule-based				Building blocks				
Learning								Social and individual cognition informs learning

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