

8 System of Systems Management

Brian Sauser, John Boardman, and Alex Gorod

Stevens Institute of Technology, USA

Abstract: Knowledge for the engineering of systems is advancing rapidly but in recent years has failed to keep pace with the increasing complexity and integration of the systems themselves. While we may be able to measure and possibly predict the advancement of technology intensive systems, we are unable to effectively measure or predict the pace at which we correlate or advance our management practices of these systems. Only in the last ten years have time-honored organizations such as the Project Management Institute (PMI), the International Council on Systems Engineering (INCOSE), and the International Organization for Standardization (ISO) begun to provide fundamentally accepted guidance in how we perform project management or systems engineering. The study of SoS has moved many to support their understanding of these systems through the groundbreaking science of networks. Our understanding of networks and how to manage them may give us the fingerprint which is independent of the specific systems that exemplify this complexity. The conceptual foundation of complexity is paradox, which leads us to a paradigm shift in the SE body of knowledge. Paradox exists for a reason and there are reasons for systems engineers to appreciate paradox even though they may be unable to resolve them as they would a problem specification into a system solution. It is our ability to govern, not control, these paradoxes that will bring new knowledge to our understanding on how to manage the emerging complex systems called System of Systems. This chapter will challenge the traditional paradigm to establish some key concepts that make the management of SoS different from our fundamental practices, present an intellectual model for how we classify and manage a SoS, appraise this model with an established SoS, and conclude with grand challenges for how we may move our understanding of SoS management beyond the foundation..

1. Key words: autonomy, belonging, boundary, complexity, connectivity, control, diversity, emergence, paradox, system of systems management, team

1. INTRODUCTION

Currently, the attempt to understand the lifecycle of modern systems has been through the engineering of systems or systems engineering (SE), and the process by which the organization, application, and delivery of systems can be managed has been called systems engineering management [Sage and Rouse, 2008, Shenhar and Sauser, 2008]. A key success driver in these two fields is the process by which the integration of people, processes, problem-solving mechanisms, and information come together [Kusiak and Larson, 1999]. Historically, principles of systems engineering management and systems engineering have largely been utilized and developed in the government with projects such as manned space flight, nuclear-powered

submarines, communications satellites, launch vehicles, aircraft, and deep-space probes. It is projects such as these that carry distinctions such as high complexity of the system with high technological risk, extreme design constraints, desire for complete answers, and auditability [Parth, 1998]. Although the complexity of these systems, both in knowledge and connectivity, may not have been foreseeable by some of the forefathers of systems theory, like von Bertalanffy (1968) and Beer [1966], the most complex projects that have been or will be developed are of systems to solve complex engineering problems. Thus for decades many have argued that there are fundamental differences in how we manage complex systems from simple systems [Davies and Brady, 1998, Floricel and Miller, 2001, Hobday, et al., 2000, Miller and Lessard, 2000, Nightingale, 1998, Shenhar, 1998].

Opportunistically, the knowledge for the engineering of these systems is advancing rapidly but in recent years has failed to keep pace with the increasing complexity and integration of the systems themselves. While we may be able to measure and possibly predict the advancement of technology intensive systems, we are unable to effectively measure or predict the pace at which we correlate or advance our management practices of these complex systems. We have moved to an era in which some of these complex systems are being further defined as system of system (SoS). Considering that the recognition of complex systems can be traced back to post-World War II and the complex system entitled a “system-of-systems” to the Strategic Defense Initiative in the early 1980s [G.P.O., 1989], our establishment of fundamentals is far surpassed by the realization of how to manage systems of greater complexity. Only in the last ten years have time-honored organizations such as the Project Management Institute (PMI) [PMI, 2004], the International Council on Systems Engineering (INCOSE) [INCOSE, 2006], and the International Organization for Standardization (ISO) [ISO/IEC, 2002] begun to provide fundamentally accepted guidance in how we perform project management or systems engineering. While these fundamental body’s of knowledge have made great advancements, Shenhar and Dvir [2007] have shown through extensive empirical research that there are fundamental distinction that exist in these bodies of knowledge and how we manage systems of increasing complexity.

There is limited theory on how SoS develop and are managed. This has become even more important as there has been increasing attention in the economic activities of firms, industries, and nations to these systems. SoS differ notably from smaller, mass-produced projects and thus require different management techniques [Keating, et al., 2003]. Therefore, the study of SoS has moved many to support their understanding of these systems through the groundbreaking science of networks and complexity. Our understanding of networks and how to manage them may give us the fingerprint which is independent of the specific systems that exemplify this complexity. It does not matter whether we are studying the synchronized flashing of fireflies, space stations, the structure of the human brain, the internet, the flocking of birds, a future combat system or the behavior of red harvester ants, the same emergent principles apply: large is really small; weak is really strong; significance is really obscure; little means a lot; simple is really complex; and, complexity hides simplicity. The conceptual foundation of complexity is paradox, which leads us to a paradigm shift in the SE body of knowledge.

Paradox exists for a reason and there are reasons for systems engineers to appreciate paradox even though they may be unable to resolve them as they would a problem specification into a system solution. Till now paradoxes have confronted current logic only to yield at a later date to more refined thinking. The existence of paradox is always the inspirational source for seeking new wisdom, attempting new thought patterns and ultimately building systems for the “flat world” [Friedman, 2006]. It is our ability to govern, not control, these paradoxes that will bring new knowledge to our understanding on how to manage the emerging complex systems of SoS. For SoS, we contend that management is replaced by governance to cope with paradox.

We will present in this chapter a paradigm shift in how we think of managing systems, in this case SoS, and begin to understand the paradoxical relationship that exist in realizing them. We will establish some key concepts and challenges that make the management of SoS different from our fundamental practices, present an intellectual characterization model for how we classify and manage a SoS, appraise this model with a SoS case, and conclude with grand challenges for how we may move our understanding of SoS management beyond the foundation. First, in our pursuit to understand how we can manage this emerging era of SoS, we believe it is important to reflect back on our understanding of system theory and systems thinking to help us to distinguish what makes a SoS different, and just like our understanding of systems, it must transcend domains [Boardman and Sauser, 2008].

2. BUILDING A FOUNDATION: A SOS PHILOSOPHY

There is a saying: “When the going gets tough, the tough get going.” For traditional systems engineering managers this means that the classical response to a complex challenge is to knuckle down, be determined, muster your strength, and dig in until the challenge is overcome. This philosophy characterizes so much of engineering culture in the face of increasing complexity in the challenges that this community confronts. For SoS this becomes an entirely incorrect response; more than that, it is wholly counter-productive. The tougher you become in the face of tough going, the tougher the going becomes, with only defeat and catastrophe awaiting. SoS represent a uniquely complex challenge, in terms of conception, design, development, deployment and management. The correct response to this challenge is counter-intuitive insofar as contemporary engineering culture is concerned. It is not to rise to the challenge in terms of increased complexity – of logic, strength, effort, or the usual dimensions that call for reinforcement. The correct response is essentially asymmetric: to be deliberately simple; to think counter-intuitively; to behave paradoxically; to change the way we think, what people call paradigm shift, and to invert many of the traditional actions with which we have been programmed. In one vernacular, it is ‘to work smarter not harder’. It is a matter not of reinforcement but rather reprogramming.

With increasingly inextricable links between business models and technology development there are three forces at work: First there is the lack of synchronicity between systems development - and their subsequent management – and knowledge development, to support that systems development and management. Second, confusion abounds as to what exactly constitutes a SoS, with intense polarization between two camps: those who attest they are ‘merely’ systems (and so whatever is at our disposal for systems development works equally well, more or less, for these new fangled systems), and those who assert there is a fundamental difference (but who patently fail to articulate what this is, much to the amusement of the opposition, and their personal chagrin). Thirdly, there exists a huge gap between engineers who design and develop complex systems (systems engineers or complex systems engineers?) and scientists who formally study complexity and articulate complexity theory (e.g. ‘the groundbreaking science of networks). That gap, essentially a separation of knowledge and practice, creates a force that makes any perceptible shift in understanding of what complexity really means and how its peculiar challenge can be overcome distinctly unachievable. As we see these three forces at work, and interacting in complex ways, we are bound to produce a philosophical stance that asks, and begins to explain: why do we have this asynchronicity and how might it be overcome; what is the essence of a system and how can this be leveraged to explain the fundamental distinction between a system that is truly a SoS and one that is ‘merely’ a system (of parts); and, finally, why is there

an imperative to shift our way of thinking and what are the pivots for accomplishing this paradigm shift? Is the answer in paradox?

3. PARADOX IN SOS MANAGEMENT

What is the meaning of simultaneously applicable opposites? And what has such a question got to do with SoS management; especially its application to SoS and to enterprises that either execute such development programs or are themselves enabled by the SoS? We contend that this is realized through paradox.

Paradox signifies “contradictory, yet interrelated elements” [Lewis, 2000]. For example, on a single sheet of paper appear two statements, one written on each side. On the first side we find: “The statement on the other side of this paper is true”, and on the other side we have: “The statement on the other side of this paper is false”. More endless circularity. Does this lead us anywhere? Cameron and Quinn [1988] proclaimed that the exploration of paradox can allow us to move outside oversimplified and polarized thinking to recognize the complexity, diversity, and ambiguity of life.

Here’s what we have to say about paradox –

A paradox is an apparent contradiction; however things are not always as they seem. A Paradox can be explained, but only by seeking wisdom from above; for the systems person this means looking upwards and outwards, not just down and in. Paradoxical thinking is systems thinking at its best.

When we use the word apparent we give ourselves the opportunity to introduce viewpoint or perspective which is personal or subjective to some individual (person or group), and this notion, sometimes labeled stakeholder, is germane to SoS SE. Further we hold out the hope of resolution as opposed to the sense of despair or confusion that can befall those who get trapped in the endless circularity of evident paradoxes. Handy [1994] stated that a paradox framework shifts the model of “managing” from modern definitions based on planning and control to coping. Many apparent paradoxes which once confused the greatest minds of the day were later explained by new concepts and new ways of thinking.

The essence of paradox is tension – two statements claiming to be true and at the same time contradicting each other [Schneider, 1990]. The ultimate release of that tension, not found in the resolution of the conflict within the paradox itself but rather in the recognition of the virtue of the paradox as a whole, always leads to new ways of thinking. For this reason, as much as paradox is unpalatable, especially to action-oriented people such as engineers, technologists and business executives, it can be valued as a lever to change mindsets, to shift thinking, and a potential well-spring of new ideas leading to more effective action.

We assert that to resolve this tension prematurely, for the sake of taking action, always leads to ineffective action and, more expensively, to miss an opportunity to change your way of thinking and gain breakthrough knowledge. Likewise to ignore this tension, to pretend as it were that the paradox is unreal or irrelevant is to preserve the status quo, maintain the same old grid lines of thought and inevitably head for disaster.

Paradox is a reality of our lives. Tension is too. We have chosen to feature paradox as a significant element of SoS management because we see paradox less as a source of confusion, which at face value it certainly is, and more as a portal into new ways of thinking, new modes of working, and better ways of living. A source of tension in the development a SoS is the demand to increase efficiency, cultivate inventiveness, build individualistic teams, and think globally while acting locally – a paradox [Lewis, 2000].

We want to explore what we call ‘the world of both.’ In a paradox there are two opposites that compete for our attention and each demands that we make a choice. But the very existence of the paradox itself demands that we do not choose, but that we accept both and therefore the nature of the relationship between the parts, manifested as a conflict, contradiction or something other that runs counter to common sense or conventional wisdom. Systemically, the parts of the paradox demand choice but the whole of the paradox requires acceptance of both, as illogical as that seems. It’s as if parts and whole cannot agree, and yet parts make the whole and parts they be.

In our experience neither engineers nor managers are comfortable with the notion of both, of holding onto a tension that must be resolved. As system engineers we are trained to put boundaries around the system of interest. We like choice, perhaps not an overabundance of choice, and we are required to choose. It’s our nature of being [Ford and Ford, 1994].

We believe that systems engineers and systems managers need to be, or learn to be comfortable with both. Scientists have had to learn to accept sub-atomic matter to be both particle and wave, whilst technologists in pursuit of the quantum computing dream postulate the qubit, a binary digit that is both one and zero, and consequently are able to leverage computing power exponentially. Both, if not as yet ‘in’, is on the scene, and we are offering our own thoughts and examples to make it easier for decision makers to be accepting of simultaneous opposites (i.e. conflicting perspectives) leveraging these into richer realms of decision-making.

3.1 The Boundary Paradox

The notion of boundary is inseparable from that of system. As problematic as it might be to locate or articulate the boundary of a system that it exists relative to the system itself is incontestable. The boundary may be defined by geography or other dimensions such as culture, organizational structure, or IT infrastructure, but howsoever it’s defined it fundamentally speaks of separation, of distinction, of limitation as well as approximation. The boundary shows who and what is in and out [Bernard, 1952].

If a system is a collection of parts and their interrelationships assembled together to form a whole for a given purpose, then the parts and their relationships are in (the system). What lies beyond the boundary is not part of the system. It may be coveted by the system and in due time be acquired and integrated into the new whole but while it lies outside the boundary it cannot be considered part of the system and may even be considered hostile to the system.

The parts of the system can be controlled so as to serve the system, or in self-organizing style relied upon to control themselves autonomously and bring even greater well-being to the system. The externalities cannot be controlled; they may even need to be combated, if regarded as foe rather than friend. Possibly they can be influenced thereby rendering docile an otherwise adversarial influence on the system itself.

System managers must be perpetually mindful of the boundary. The system boundary separates what belongs to the system from what does not belong. As much as the human body prefers not to be invaded by unwanted bacteria, immunization (letting a specified amount of

negative bacteria in) enables the positives to get better at dealing with the negatives so when large numbers of these try to invade, the body's defenses have significantly improved. If this is a beneficial tension of a boundary, how many should belong; what boundaries do we open; how large are the openings; what does that mean to a defined system boundary?

Our boundary paradox can be stated as follows: "You have to have a boundary (in order to nurture and develop specialisation in functional expertise, for example). BUT you must also NOT have a boundary (in order to allow that specialisation to be rendered as a service, otherwise why has it, and to allow that expertise to be resourced via interactions with others). So the boundary must exist and must not exist – it must do *both*, at the same time. The boundary must keep things out and keep things in, but it must also let things out and let things in. The boundary paradox is a realm systems engineering managers have yet to enter but to which they must journey.

3.2 The Control Paradox

How many people and how many firms do you think are involved in the end to end process of conceiving, making and selling a Grand Cherokee Jeep? From initial product concept through to a satisfied customer driving her new purchase of a dealer's lot. It's perhaps not a question that interests many but the answer usually startles most.

When Thomas Stallkamp, former Vice President of Chrysler asked this question of his line managers it took them a little while to find the numbers. In the end they came back with the answer: 100,000 firms and 2 million people. Stallkamp followed this question with, "Who's managing this enterprise?" The real answer is a paradox – no-one is *and* lots of people are. Yet another time to make your mind up? Or a time to recognize and respect the paradox, waiting until the appropriate moment to release the tension and to achieve breakthrough thinking.

No-one sits atop the Chrysler Grand Cherokee Jeep 'experience.' Perhaps notionally someone does, but in no way can they be said to be its manager. Littered throughout the management hierarchy, or network if you prefer, are hundreds of personnel each with their individual spans of care. But in what ways can this diverse collective be said to be in control of the whole experience when it's probably the case that they are largely unknown to one another? Do these managers perform like ants and somehow support excellent behavior for the Cherokee colony? And if so, understanding that the ant has no commander directing colonial affairs are we to understand control to be just as effective, if not more so, if it is distributed rather than precisely located in a central commander? And can we really trust distributing control to a constituency that is largely unaware of the affairs and actions of its neighbors?

So when we ask 'can we really trust distributing control to ...' maybe we are asking the wrong question. Just like when Stallkamp asked who (in particular rather than plurality) is in control of this vast extended enterprise (or SoS); maybe he was asking the wrong question. We ask the wrong questions when we are in the wrong mindset. And the purpose of paradox is to confront that mindset. To force us to ask wrong questions. And to be prepared to change our mindsets, thereby releasing the tension in the paradox and moving to breakthrough thinking. So what are the right questions? Well, stepping back: what is the right mindset? Maybe control is or at least starts with self – self-control. After all, you have to exercise self-control in response to an order, be it in the military, civil or family domains. What's more the one issuing the order expects this, relies on this self-control and in some way is developing this in the one to whom the imperative is directed. Command assumes self-control. The question now is, "Is there an extension to command that is of a controlling nature (i.e. the communication of command carries with it or in it a controlling influence).

At this point we are beginning to recognize the polarities. One is the command and control version by which authority located 'at the top' issues directives which get resolved into executive action by a large group of people. The other is the self-organizing notion of an idea which (from the bottom) infects, propagates and galvanizes a large group of people who then take action, as though they were a unit and had been commanded by a governing authority.

Put in other ways –

- authority must exist at the top representing order but it must also exist at the bottom representing autonomy;
- command must exist and orders from an external source be obeyed but so also must the power to be insubordinate operating alongside a self-will that knows its own order and orders;
- finally, control must operate within a framework (a one) that grants liberty to its constituents (the many) but control must also be manifest in the self- (a one) in terms of self-control and self-discipline to make a framework (for the many) work.

What are the ways in which this paradox might be resolved and its tension released? We propose that find a lesson from history in the command of Admiral Horatio Lord Nelson to be of guidance in these three concepts [Kimmel, 1998]:

- **Creative disobedience** flowed naturally from his philosophy of independence of command. If his subordinates should have the freedom to deal with situations as they came up, he should be able to take the initiative as a subordinate in a battle, even if it meant ignoring orders.
- **Reciprocal loyalty** is the idea that one must give loyalty down the command hierarchy in order to gain true loyalty (as opposed to obedience through fear).
- **Servant leadership** that has been so supremely exemplified in the inspirer of the many faiths whose teachings can be incomparably paradoxical.

3.3 The Team Paradox

'Together each achieves more.' This phrase epitomizes togetherness. It gives a sense of fulfillment that is somehow eluded by the mindset of going it alone. It seems to make selfishness redundant and self-achievement more rewarding because self is being helped by others and self is helping others simultaneously. It also conjures the notion of being coached or mentored or somehow developed as a consequence of which life is more rewarding, learning is gained, and transferable skills acquired. It's almost so engrained nowadays that you can't be in a team without realizing that while more is the goal of each and everyone it comes at the expense of being together.

A team simply has to be a system. It may be a poorly performing team and therefore a failing system, but a system nonetheless. It's worth our while spending some time looking at what a team is and what it means, as an example of a system, to discover yet another interesting and rather fundamental paradox which can so easily go unnoticed by system designers and operators, as a consequence of which we have more bad systems than we need.

In a team we find both sameness and differentiation. Sameness is exhibited in uniformity. Everybody on the team and associated with the team identifies with the unifying themes and artifacts. They become recognizable and identifiable. They help to define the personality of the

team distinguishing it from other teams. It is an emergent oneness that covers the many identically. Sameness is also exhibited in the common aim of success, of achieving more. A team has no room for mavericks, loners, rebels, dissidents and the like; regardless of individual expertise, no matter how exceptional. A member not committed to togetherness cannot be on the team. Indeed different team members have differing views on what constituted team success. Ironically this apparent sameness can be highly distinctive, though improbably divergent. But this distinctiveness is unimportant because at a deep rooted level the sameness, the single commitment to team success and achieving more together, is overpoweringly unifying.

From time to time the sharp distinctions in subjective interpretations of togetherness can be a powerful disintegrating force. That's the price of differentiation operating simultaneously with sameness. The tension between the two is, in this instance, disruptive in the most unhealthy fashion. However patterns exist to provide early warning signs, detect the potential demise and make timely interventions. But differentiation is essential for many reasons. Sameness is needful. But not singularly so. A team is a blend of many skills. In an engineering team you need people from different disciplines: electrical, electronic, mechanical, and software. You also need people with different project experiences – in leadership, in work package management, in test, and in manufacturing. Teams need different skills, knowledge bases, and experiences. The team becomes a pool for blending these differences together, so that each achieves more.

A team simply has to be a system because it has to have requisite variety, i.e. differentiation, parsimony – a meanness that culminates in the single-mindedness of each member to put the team first, and harmony – that which makes togetherness feasible. What is true for a team of individuals is true also for a collection of systems gathered together to form a new system (or SoS) – there is both differentiation – of functionality, and of sameness – performing the functions on behalf of achieving SoS purpose, of fulfilling the SoS's mission.

So what of paradox? There is an indisputable duality about the individual (or system). One aspect is that distinctive individuality (or autonomy). The other is that of membership, of belonging, of being a part. The thing belonged to, the team, benefits from that individuality, but only when it is brought into play as part of the team, via membership. So that individual has to maintain individuality and at the same time sacrifice it via membership. Indicating the primacy of the team over the individual. But if that sacrifice is wasted, the team primacy is immediately suspected. Howsoever the belonging is expressed, it is very real and not without expense to that individual.

Let us also realize that there is not one single individual but many. This duality is replicated many times with these instances being highly varied. It is through this variability that the system has its being. Not merely in the existence of members, nor in the distinctive roles that they play – helping the team towards dynamism – but in the diversity of expressions of this very duality of the maintenance and rendition of many distinctive individualities. Diversity is more than difference. Diversity is the measure of the paradox of the one and the many.

Here is how we express the paradox of diversity. First we recall that a system is a collection of entities and their interrelationship assembled in such a way that the whole is greater than the sum of the parts. This notion of 'greater than' has been summed up as more is different [Anderson, 1972]. The parts belong so as to serve the purpose of the whole. Yet this purpose is not well served if the parts belong for that reason alone. The homogeneity of partness is good, it ensures each and every individual is signed up as a part. But homogeneity is not something we want of the system itself. In order for it to survive and prosper, heterogeneity is required. How does the system inherit this heterogeneous quality? Our understanding is that this occurs when each and every part expresses simultaneously its individuality and its partness in manifold and diverse

ways. This diversity is what gives the system its heterogeneity. Thus a tension is set up for each of the many between autonomy, maintaining individuality, and belonging, rendering this distinctiveness to serve the many. This aggregated tension creates the whole. The system is continually in tension, produced by this paradox of diversity.

4. BUILDING A CONTEXT: SOS CHARACTERISTICS

So we esteem to understand how we may understand the paradox that resonates in the realization of a SoS in order to full the management of a SoS. Thus, in this section we propose a context based on a characterization of a SoS so we may identify its paradoxical challenges. In our first cognition of what a SoS was by definition, we were enlightened by others that had previously defined SoS, such as Bar-Yam [2004], Carlock and Fenton [2001], DeLaurentis [2005], Maier [1998], Sage and Cuppan [2001] to name a few of the over 40 definitions we discovered [Boardman, et al., 2006]. While many have pursued a definition of SoS, like Sage and Cuppan and Bar-Yam, we have pursued a characterization of SoS. In an earlier paper, we presented these characteristics that enable the differentiation between a SoS and a system and then used qualitative techniques in pattern formation of text to validate cross references from our literature search where we believe others were articulating our chosen discriminating characteristics [Boardman and Sauser, 2006]. We will describe these characteristics in the realization of managing a SoS in the following sections. Exhibit 1 is a summary of the five characteristics, their definition, their motivation, and the origin of their understanding.

Exhibit 1. Foundations and Descriptions of the SoS Characteristics

Characteristic	Definition	Motivation	Provenance
<i>Autonomy</i>	The ability to make independent choices; the right to pursue reasons for being and fulfilling purposes through behaviors.	Legacy systems are indispensable to a SoS; the SoS has a higher purpose than any of its constituent systems, independently or additively.	Managerial and Operational Independence
<i>Belonging</i>	Happiness found in a secure relationship.	Legacy systems may need to undergo (radical) change in order to serve in a SoS.	Shared mission
<i>Connectivity</i>	The ability of a system to link with other systems.	Legacy systems targeted for an envisioned SoS are very likely highly heterogeneous and unlikely to conform to a priori connectivity protocols; the SoS places a huge reliance on effective connectivity in dynamic theaters of operations.	Interdependence, Distributed, Networked, Multiple Solutions, Interoperability
<i>Diversity</i>	Noticeable heterogeneity; having distinct or unlike elements or qualities in a group; the variation of social and cultural identities among people existing together in an operational setting.	Legacy systems were most unlikely to have been purposed to work together prior to targeting the envisioning of the SoS; the SoS can only achieve its higher purpose(s) by leveraging the diversity of its constituent systems.	Independence, diversity, heterogeneous
<i>Emergence</i>	The appearance of new properties in the course of development or evolution.	A boundary is indispensable to a system; all systems are emergent; emergence requires a well defined boundary; a SoS has dynamic boundaries but always clearly defined; ergo, a SoS should be capable of developing an emergence culture with enhanced agility and adaptability.	Evolving, Intelligence, Synergy, Dynamic, Adaptive

4.1 Autonomy

The reality of legacy systems relative to an envisioned SoS is inescapable just as individual freedom of choice is incontestable. For human beings autonomy is defined as a person's ability to make independent choices. What of a system? Each legacy system that is envisaged to become a constituent system in the SoS must be accorded autonomy, the right to pursue reasons for being and to fulfill purposes through behaviors. Respect for this autonomy is paramount and it is a respect that the SoS itself must pay. That is not to argue that the legacy systems cannot be migrated or morphed to more aptly serve the SoS, but it is to argue that such transformation must be out of respect for that constituent system's autonomy. To do otherwise is to imperil that constituent system's functionality and essence of being which might then be lost to the SoS, a foolish thing since it is these features that are wanted for inclusion. We argue that the capabilities of the SoS are enhanced by the exercising of constituent systems' autonomy, and that the opposite is true of a system that is not a SoS, whereby its parts must cede whatever autonomy they might have had in a totally subservient act of granting autonomy to the system.

Smuts [1926] introduced the term 'holon' which later was explained in more detail by Koestler [1990] as being that which is both whole and part. This term aptly fits constituent systems relative to a SoS. However, it is proposed that a SoS cannot be so called on the basis of structure alone, including hierarchies and holarchies. It must also qualify on the basis of dynamics, for which the remaining distinguishing characteristics provide further explanation.

4.2 Belonging

Just as legacy systems are a reality so also is the problematique which goes unsolved by these systems, singly and additively. By the same token the envisioned SoS is a reality if only in concept. Someone or some persons see that the SoS, by making use of the constituent systems via a new framework, will in a real sense deal with the problematique. So there are two new realities: the problematique and the envisioned SoS. This makes the second differentiating characteristic, belonging, a key one. The SoS cannot translate from conceptual reality into physical reality without the constituent systems belonging. But why should they? What's in it for them? Who can make them belong? What will become of them once they do belong, given that they won't lose autonomy? How will they belong? Will they continue to belong, come what may, or will their belonging be strictly conditionally? Can they exit without hurting the SoS and/or themselves?

The parts of a system (that is not a SoS) have no choice in the matter of belonging since they have no reason for existence and no dynamics to contribute without belonging. Parts in such a system are integral and the system cannot function without them. In a SoS the parts, also wholes and therefore holons, are integrable, i.e. capable of being integrated. It is proposed that for a SoS there must be negotiation between it and each constituent system about the latter's belonging and the former's acceptance. There will be manifestations of the problematique when it is better for a constituent system to unbelong or for it to be believed that they do not belong when they actually do. We must continually bear in mind that the existence of the SoS is to confront a perpetual problematique for which no single point solution, no single system, is adequate. It is not about the system as such but about the SoS capabilities for resolving or addressing the problematique. Hence 'belonging' becomes a core competence or stratagem available to the SoS for dealing with the problematique.

4.3 Connectivity

For the U.S. military, interoperability translates into net-centricity [Stenbit, et al., 2003]. They want the same powers of connectivity between their warfighters, commanders and others who ‘need to know’ that global commerce has acquired via the Internet and the World-Wide-Web, instruments which have transformed business models. No surprises there, except there is an irony considering the Department of Defense’s (DoD) chief concern is with an enemy that is organized as a network, testimony to the maxim ‘fight fire with fire?’ Later we will get into the practical application of the ‘connectivity’ distinguishing characteristic but for now we want to explain its central importance.

Most designed systems require the relationships between elements to be designed simultaneously with the design of the elements themselves. Thence connectivity between components is considered alongside the design of these components, regardless of the topology of the connections be this integrated, distributed, hub and spoke, or whatever. This design pattern normally leads to hierarchies (or holarchies) and a valued stability in development whereby parts or sub-systems are themselves stable enabling a gradual build up of the designed whole, which of course must also be stable. However many such wholes or systems (that are not of the SoS kind) have designed connectivity to their environment, and this is fixed; it cannot emerge. The problematique that confronts a SoS will ensure that such limited, presciently designed connectivity leads to inevitable system failure.

Therefore we argue that a distinguishing feature of a SoS is that the internal connectivity of the SoS is not presciently designed but emerges as a property of present interactions among holons. Net centricity is a form of prescient design, enabling full connectivity by supporting interactions and connections between all the elements, according to defined protocols. Further it supports extension as more holons are added to the SoS, provided that is these holons conform to the protocols. In our scheme for a SoS this connectivity is itself adapted as holons enter and exit the SoS. And this takes place in a way that enhances the connectivity or interactivity of the SoS with its environment, i.e. dealing with the problematique. In the context of this discussion, connectivity has to do with a lot more than just topologies and protocols and interoperability standards, although it does address these practical matters, and is more concerned with the agility of structures for essential connectivity in the face of a dynamic problematique that defies prescience.

4.4 Diversity

Imagine soldiers who are not soldiers but who wage war that is not war. Citizens who are loyal to no nation state to which they notionally belong but who really belong to the vision of an integrated, faith-based, global-wide superpower governed by a single ruler headquartered in the Middle East. Imagine warriors who are not trained in their country of origin but in foreign lands including that of their enemy and trained by that enemy in skills needed for battle. Fighters who have no armor nor weapons to speak of save the legacy systems of their enemy, namely the Internet, cell phone technology, Boeing aircraft, the air transport infrastructure, up to a point and box cutters. Can you imagine that? If we had could 9/11 have been averted? Our problem in perceiving these threats to an extent lies in our inability to cope with diversity. Ashby [1956] posited a law of requisite variety asserting that for a system to be sustained it must have at least the same number of degrees of freedom as the environment in which it operates. To paraphrase, interior diversity must match exterior diversity, or the boundary which separates them is futile. Post 9/11 efforts have largely concentrated on the boundary – understanding it, strengthening it,

and in one sense extending it, for example, by military occupation of some nation states. Greater attention is now being given to increasing interior diversity and reducing exterior diversity a role, we argue that falls to SoS thinking and acting.

Engineers have a problem with diversity, summarized in the maxim ‘keep it simple, stupid (KISS)’. In an age when complex systems give rise to simple patterns and simple systems produce complex behavior [Waldrop, 1992], perhaps it is time for diversity to be seen less as a problem and more as an opportunity. There is still ample scope to apply KISS and this will undoubtedly continue in traditional systems engineering. Given that legacy systems ab initio present a given and possibly great diversity, what should the SoS designer do? The purpose of the interoperability framework is to get the legacy systems, holons, to work together, and to do so not additively as in the current underachieving case, but synergistically. Does this mean reducing diversity, and if so how can the SoS match the huge diversity in the problematique it faces? The opportunity for the SoS is to increase connectivity which probably translates into standard protocols and specific architectures or topologies, an imperative for uniformity, and increase diversity. This respects the autonomy of the holons, allowing them to maximize their contributions to the SoS but within the context of the SoS.

Increasing diversity is not a license for anarchic design, but it is a spur to realizing resilient capability. Situational awareness is enhanced by multiple perspectives. But in the end a common operating picture that informs command decision is just that: a final conclusion. But no-one wants to make decisions based on a conclusion that is not richly informed, that is lacking a vital piece of data, information, knowledge or wisdom. Diversity, through a variety of viewpoints, processes, technologies and functionalities ensures richness, and the SoS must be able to leverage this, in an unencumbered fashion.

4.5 Emergence

The terms emergent and system are inseparable. By definition when parts and their relationships are assembled together what emerges is the system. All systems are emergent. Herbert Simon [1996], a Nobel Prize winner, said this another way when he argued that complex systems will evolve from simple systems much more rapidly if there are stable intermediate forms than if there are not; the resulting complex systems in the former case will be hierarchic.

The properties, behaviors and purposes attributed to systems can also be said to be emergent. Some of these, for designed systems including the engineered variety, are intended. For example, it is intended that an automobile serves the purpose of transporting goods and people across reasonable distances and terrains safely, comfortably and in timely fashion. This is an emergent or resulting property of that system. The same emergent property cannot be attributed to any of the parts therein, although every one of these will have its own emergence. Each one is engineered to a specific purpose, to deliver an emergent property: for example the power train to provide propulsion, the wheels to provide traction, and the steering to provide guidance control. With this example in mind one can move up and down the scale of systems enumerating specific emergent properties for each part, sub-system, and system.

Some emergent properties are unintended and of these some are undesirable and others serendipitous. Relative to the auto, perhaps the chief undesirable and unintended behavior is atmospheric pollution most acutely experienced in city traffic. At that level traffic jams are another example of unintended emergence: not a single vehicle is responsible for a traffic jam, it takes a bunch of interacting autos to make one of these. Yet a desirable emergent property at that level is a personal mass transit system, highly convenient if not altogether rapid, one that obviates

the need for investment in alternatives such as subways (for cities) and rail networks (for inter-city travel).

The question arises, if all systems are emergent, is there anything different or special about a SoS? A SoS must match the agility of the problematique which calls for greater emphasis on strategic capability than on rigid tactical measures. The exact nature of the SoS is often determined in real-time and indeed at higher clockspeed than that of the environment (or the threat within that environment). The simplest way this can be further explained is to draw a comparison between a system and a SoS.

A system provides a response to a set of predetermined 'requests' i.e. threats or opportunities arising from the environment in which it operates. By contrast, a SoS is an anticipatory responder having an a priori undetermined and unknowable range of responses subordinated to auxiliary mechanisms for anticipation, including disturbing the ability of the environment to pose threats or limit opportunity. In the next section we will use a case example of a proclaimed SoS to show how these characteristics may define and realize a SoS.

For a SoS, we contend that the realization of these characteristics or the life cycle of a SoS is an evolutionary, self-synchronization by which the SoS will define itself when it has reached a state of optimum performance. This differentiates SoS from other systems because it is not the manager of the system which governs the life cycle. In an evolutionary state, the rates at which change will occur, the order of change, the legacy-information upon which changes are imposed, and the environmental challenges during the periods of the change are all unknown. The error in the design of a SoS is that change may be seeking a specific goal, and basic to the assumption of evolution is that no goal exists. The lack of a goal limits the analysis and ability to calculate a likelihood or failure, thus most of the assumptions in a SoS are not verifiable.

4.6 Characteristics as Paradoxes

Glass' chaos theory [1996] explains that most organizations believe there is a state of equilibrium that management tries to balance around. Fundamental to Glass' theories and chaos theory is that the environment is not inherently stable and there is a fine balance that produces order from disorder. This becomes a balance on the edge of chaos while letting a certain level of disorder bring order and direction. Brown and Eisenhardt [1998] refer to chaos theory in management as *structured chaos* (figuring out what to structure and not to structure, both on an organizational level and a managerial level).

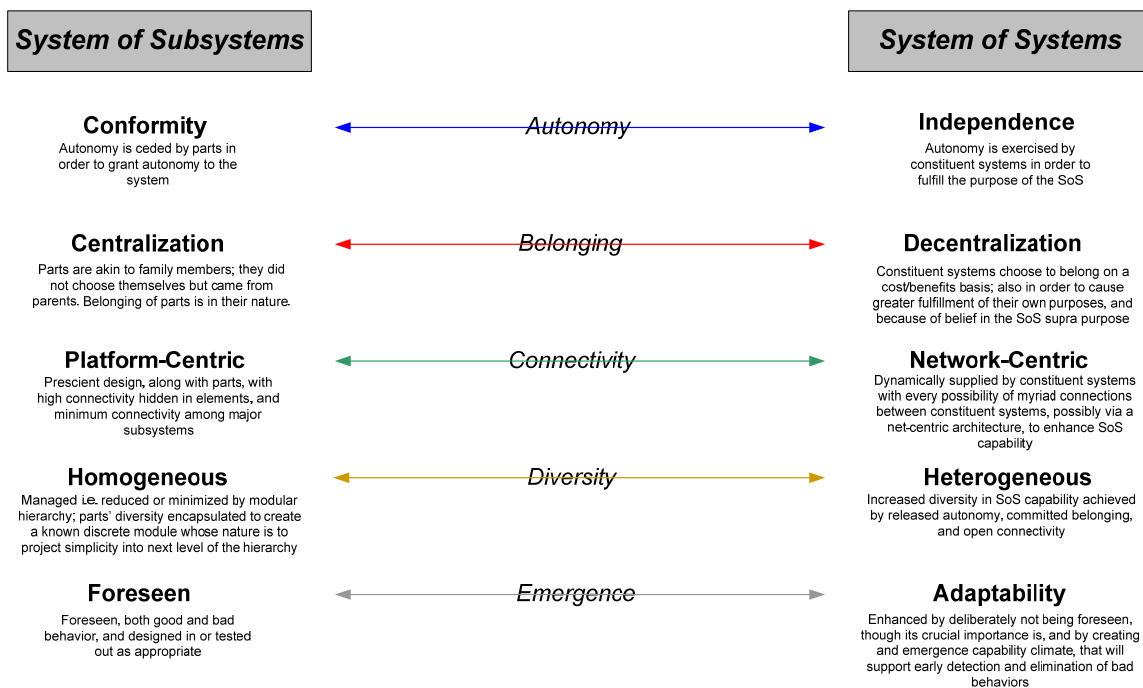
Likewise, for each of the five characteristics presented in Section 4, there are opposing forces or paradoxes that are influenced by fluxes in realizing or recognizing a system [Sauser and Boardman, 2007]. While this balance may be considered reversible, the reversible is conditions under which the forces are so nearly balanced that an infinitesimal change in one or the other would reverse the realization of the system. In any system, we seek ideal conditions that the realization of the system is carried out reversibly. Under these conditions, the realization of the system yields the maximum possible performance; although, reversibility does not hold true in practice. The flow of these forces and their relationship work in distinguishing types of systems and determines the togetherness of a system which fortifies its realization.

We want to establish a fundamental construct that provides a scaffold for paradoxical reasoning that further distinguishes systems from SoS. Our reason for doing so is twofold. First it is important to develop frameworks that provide a holistic view of the subject matter since we know that in any whole the parts are interconnected and thus the effects produced by however small a

change can be highly significant and lasting. Interconnectedness, interdependency and for that matter interoperability demands a holistic approach. Secondly, the principles that have served as well before complexity theory are being assailed by uncertainty, indeterminacy and paradox. This is not to say that they are rendered useless but that they have to be reviewed with these dynamics in mind.

By comparison we believe the characteristics presented in Section 4 have a paradoxical nature that governs their expression and potential architecture. Exhibit 2 shows the paradoxical tensions that exist for each of the characteristics and what it means to describing types of systems. That is by suppressing or avoiding one side of a polarity intensifies pressure from the other [Hofstadter, 1979].

Exhibit 2. System Characteristics and their Paradoxes



Likewise the expression of any one of these characteristics is interrelated to the expression of another which exemplifies the tensions. For example, the level of autonomy may determine the degree of belonging which will affect the extent of connectivity and possibly restrict the diversity (of elements) and maybe the emergent properties (of the system). But equally a shift in diversity may have an effect in belonging and hence connectivity leading to a raising of the autonomy level and consequential effect on emergence. The coding in these pathways depends on the levels in the characteristics to which they connect but it also has an effect on these levels being maintained or changed, up or down. Exhibit 3 shows the interdependence of these characteristics. In the following sections we will further describe the paradoxes that exist in the realization of these characteristics.

Exhibit 3. The Interdependence of the Characteristics [Sauser and Boardman, 2007]

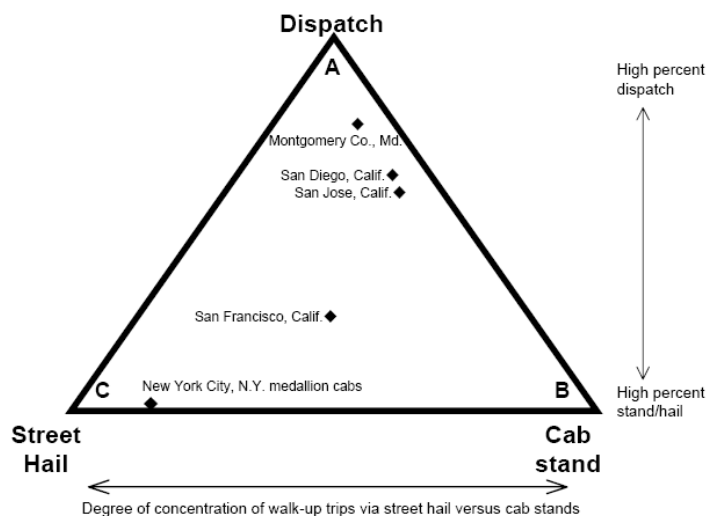
Characteristic	Determines the Degree of...	Interdependent with...
Autonomy	Perspectives of systems are maintained and stay independent from each other	<i>Diversity</i>
	Mistakes may become correlated with each other	<i>Emergence</i>
	Portfolio of systems is balance between unique and general	<i>Belonging</i>
Belonging	Conformity is forced upon requisite systems	<i>Autonomy</i>
	Responsibility is formalized for controlled belonging	<i>Diversity</i>
	Capability allows for distinguishing the good solutions from the bad; "Survival of the Fittest"	<i>Emergence</i>
Connectivity	Self-organization and decentralization	<i>Belonging</i>
	Self-interest and independence	<i>Autonomy</i>
	Who, what, where, when, and how – allowing the coordination of activities on one hand while solving different problems on the other	<i>Diversity</i>
Diversity	Preservation of independence is permissible	<i>Autonomy</i>
	Collectivism becomes a destructive characteristic (e.g. "group think")	<i>Belonging</i>
	Legacy of new systems is not redundant to that of the existing systems	<i>Connectivity</i>
Emergence	Knowing and knowing that you know are different skills	<i>Diversity</i>
	Trying to find the optimal systems will lead you astray (and trying to find the true systems will not)	<i>Connectivity</i>

5. DESCRIBING A SOS – A CASE STUDY OF THE NYC YELLOW CAB SYSTEM

New York City Yellow Cab System of Systems (SoS) is an essential part of the NYC transportation network. It consists of over 13,000 licensed medallion taxicabs [Commission, 2007]. It serves about 240 million passengers a year which creates a 1.82 billion dollar industry [Consulting, 2006]. NYC Yellow Cabs bring in around 30% of all fares paid by passengers for all trips in NYC, and approximately 45% of fares paid for trips within Manhattan [Consulting, 2006]. On average, Manhattan residents hail a cab 100 times a year [Consulting, 2006]. The taxicabs are privately operated by independent companies or individuals. At the same time they are closely regulated by New York City Taxi and Limousine Commission (TLC). In contrast to

other major cities of the United States, NYC Yellow Cabs operate predominantly on a street hail basis and do not operate on a dispatch basis as illustrated in Exhibit 4.

Exhibit 4. Schematic diagram of taxi customer market segments [Schaller, 2006].



Using the five characteristics and their paradoxes, we will describe the New York City Yellow Cab SoS. We will touch upon the opposing forces/paradoxes within each characteristic and then heuristically indicate a point where those forces meet.

5.1 Autonomy

All of the Yellow Cabs are operated by independent entities. Although strictly regulated by the TLC, they make their own decisions on how to operate. There are two opposing forces within the autonomy characteristic, which are:

- **Conformity-** The TLC is a government agency that was created to regulate and improve taxicab service within NYC. The main objectives of the TLC are: to set the regulations such as the taxi fares, inspect the vehicles for safety reasons, issue licenses, and establish the local rules and regulations. The TLC enforces that each taxi cab is inspected three times a year. Also, it receives and investigates passenger complaints. It has a right to impose fines, issue summons, and has the authority to suspend or revoke licenses for rule violations [Commission, 2007].
- **Independence-** Although, the Yellow Cabs are closely regulated by the TLC, each medallion cab operates on an independent basis. They make independent choices in regards to schedule, routes, breaks, service, etc. According to the survey done by Schaller Consulting [Consulting, 2006] one of the main reasons licensed drivers want to drive a taxi cab is because of the independence/flexibility aspect of operating a taxi cab. Based on the same survey, data (in percentage) shows that independence is more important than making money.

As a result, the point where conformity and independence meet leans toward the independence side within autonomy.

5.2 Belonging

The entire NYC medallion cab SoS shares the same mission, which is to serve NYC customers. It has to be done in a safe, efficient, and affordable manner. Licensed operators have the option, ability and the rights to either belong to the SoS or not. For example: NYC ridership took a downfall between 1963 and 1977 as New York City went through a deep economic decline in the 1970s and many taxicabs were sold or operated one shift instead of two shifts per day. It triggered a sharp decline in medallion prices. They went from \$30,000 in 1960s to \$10,000 in 1971 [Consulting, 2006, Consulting, 2006]. Today, the medallion price can be as high as \$420,000 for individual and to almost \$600,000 for corporate (fleet-owned) license [TLC, 2007]. Giving individual cab owners/operators incentives based on the overall Yellow Cab SoS performance encourages cooperation among them toward a common goal. The opposing forces for belonging are:

- **Centralization-** NYC Yellow Cabs are regulated by one single agency, TLC. It acts as a centralized body which sets the overall transportation policy governing NYC Yellow Cab services.
- **Decentralization-** Taxicabs are privately operated and can not be prearranged for pick up. They provide transportation exclusively via street hails/cab stands, because there is no central dispatcher.

Overall, there is a minimum set of constraints and maximum freedom for Yellow Cab drivers and/or operators to make decisions. As a result, the meeting point for the opposing forces is close to the decentralization side.

5.3 Connectivity

Operating yellow cabs in NYC are connected through the transportation and social networks. The New York City infrastructure which includes roads, bridges, tunnels, gas stations, parking lots and repair shops all enable the Yellow Cab SoS to work in a continuous manner without any interruptions. The social networking provides access to the worker's alliances to protect drivers' rights, traffic news reports, hints on how to avoid traffic and tips where the most customers are (i.e. events, concerts, games, etc.). While there is a strong net-centricity in the structure of the Yellow Cab SoS, each driver pursues his/her own interests. Therefore, the opposing forces for the connectivity are:

- **Platform-Centric-** Driver's income, which averaged \$158 per shift in 2005, [Consulting, 2006] depends on the cab mileage driven with passengers. It is also referred to as "paid mileage." In 2005 only 61% of the total cab mileage was "paid mileage" [Consulting, 2006]. Consequently, there is a fierce competition among the yellow cab drivers for customers.
- **Network-Centric-** On the other hand, all of the yellow cabs have the same power of connectivity. All have the same equal access to the infrastructure. Each Yellow Cab within the SoS is a whole on its own and also a part of the SoS network. Operating cabs form a taxi network and share the same goal which is to serve NYC customers, while individually optimizing different success criteria.

Therefore, the opposing forces of the connectivity intersect in close proximity to the network-centric side. The heterarchy of the NYC Yellow Cab structure combines the hierarchy and the network.

5.4 Diversity

Although, all NYC taxi cabs are yellow in color, there is noticeable heterogeneity in a number of aspects such as:

- **Diversity of Cars-** (i.e. hybrid, van, SUV, old, new, etc.) - The majority of the taxicabs are Ford Crown Victoria. It accounted for 92% of all taxicabs in 2005 [Consulting, 2006]. The rest of the vehicles comprise of Toyota, Mercury, Saturn, Lexus, Honda and others. Some of them are hybrid, vans, SUVs, etc [TLC, 2007]. As of April 2005, 72% of all cabs were cars year 2003 or newer, 19% were models produced in year 2001/2 and 9% were year 2000 or older [Consulting, 2006]. Of all the cabs, only 52% passed the initial inspection in 2005 [Consulting, 2006]. Recently, Major Bloomberg has proposed a law that states that by 2012 all NYC operating taxi cabs must be hybrid [Mayor, 2007].
- **Diversity of Drivers-** (i.e. background, ethnicity, age, experience, etc.) - In 2005 48% of the drivers were identified as Asian, 25% as Black, 18% as White, 7% as Hispanic [Consulting, 2006]. During the same year, the average age for licensed driver was 44 [Consulting, 2006]. According to the 1991 data, only 44% of the new applicants indicated that they had previous taxi driving experience [Consulting, 2006]. Another interesting fact is that only 9% of the drivers were born in the United States [Consulting, 2004b, Consulting, 2006].
- **Diversity in Operators-** NYC taxicab operators can be divided into three groups [Consulting, 2006]:
 - Owner operators- The owner of the medallion is also the driver.
 - Fleet-type operators- Leased to the drivers by the shift.
 - Long-term leasing- Leased to drivers for a period of months.

Mileage differs substantially between operators. Usually fleet-type operators utilize two shifts per day seven days a week averaging 72,000 miles per year. Long-term leased cabs average 62,000 miles per year. Lastly, owner operators use their cars only one shift a day five to six days a week averaging 42,000 miles per year [Consulting, 2006]. Thus, the tensions for the diversity are:

- **Homogeneous-** Medallion cab operators are predominantly male. Only 1% of drivers were female in 2005 [Consulting, 2006]. Standards which are set by the TLC (i.e. requirement for all medallion taxicabs to be painted yellow, driver licensing requirements, safety requirements, etc.) also contribute to the level of homogeneity of the NYC Yellow cab SoS.
- **Heterogeneous-** The diversity of cars, drivers (aside from gender), and operators makes NYC Yellow Cab SoS very heterogeneous.

As a result, the point where paradoxes within the diversity characteristic meet is very close to the heterogeneous side.

5.5 Emergence

As we have mentioned earlier, all systems are emergent, and this emergence is classified as intended and unintended. The intended emergent property of a NYC Yellow cab SoS is to safely, comfortably and efficiently transport NYC passengers. A single cab can not achieve this result

on its own. In the Yellow Cab SoS, the removal of one cab will not change the overall performance of the SoS. When a single cab is taken out of service, another one will emerge to take its responsibility.

In 1998, a New York Taxi Workers Alliance emerged to protect the interest of the taxicab workers. The formation of this union was the result of the April 1998 TLC's declaration which involved passing of new rules to increase the summons to the taxicab drivers for small violations. Thus an organized strike with about 40,000 taxi cab drivers was formed lasting for 24 hours [York, 2007, Press, 1998]. This is an example of unintended emergent behavior.

Also, as we write this case, another unintended development emerged. This issue concerns the use of technology within the cabs. Recently, the TLC has announced plans to require the global positioning system (GPS) to be installed in every cab. The New York Taxi Workers Alliance opposed this because the taxi cab drivers believe that the new device will track their whereabouts, and it will be very costly to install [Jones, 2007]. This new law could potentially affect the emergence and all the other characteristics of the yellow cab SoS. Therefore, the union has threatened to strike against this law.

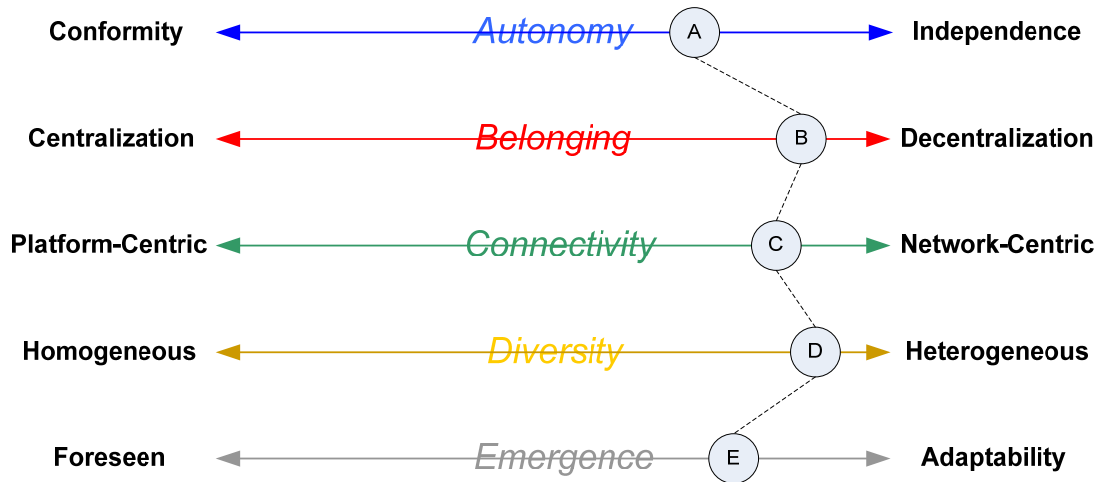
Finally, the tensions for the emergence are:

- **Foreseen-** Taxi riders expect from NYC Yellow cabs personal security, comfort, cleanliness inside the vehicles, fast and reliable service and being charged the correct fee.
- **Adaptability-** As opposed to the foreseen factor, in reality, customer satisfaction of NYC Yellow Cab service is not always met. In 2004, the New York City Transit Transportation Panel Survey revealed that in comparison to the other means of transportation the New York City's overall taxicab customer satisfaction rating is below private cars, subway, car service and local buses [Consulting, 2006, Panel, 2004, Consulting, 2006]. Also, in 2004 passengers filed over 18,000 individual complaints with the TLC [Consulting, 2006].

As it is evident from the analysis above, the NYC Yellow Cab SoS is highly adaptable to the environment, whether it is intended or unintended. As a result, the NYC Yellow cab SoS leans toward the adaptability side within the emergence.

Exhibit 5 is a qualitative representation of the Yellow Cab SoS as we have described in the five characteristics and their paradoxes. Due to the high number of constituent systems, highly dynamic and complex environment and the involvement of the human factor, this picture can be viewed differently in the future. The NYC Yellow Cab SoS is constantly attempting to find a point of balance where the opposing forces meet and find equilibrium. A non-profit group called "Design Trust for Public Space", in collaboration with the TLC, is working on the taxi system report called "Taxi 07: Roads Forward" [Space, 2007]. The report examines the present taxi system situation and accesses the developmental and enhancement strategies for the next decade.

Exhibit 5. Distinguishing characteristics of NYC Yellow Cab SoS.



6. CONCLUSION

There exist a lack of development as being a product of two entities: first because knowledge developers are looking in one direction, namely reinforcement, the addition of knowledge is essentially incremental, whereas the growth in complexity of systems is very real, driven by exponentially rising customer expectations coupled with unbridled innovation in companies; secondly, because knowledge developers are looking in one direction, and not other directions also, such as what the complexity science knowledge developers have discovered and are continuing to explore, there is inevitably a paucity of thinking and of thought processes which could otherwise provide an immensely valuable asset for the systems engineering community.

We believe that there is a fundamental distinction to be made between a system (of parts) and a system of systems [Boardman and Sauser, 2008, Boardman and Sauser, 2006]. In keeping with the spirit of complexity that significant difference is to be found in the obscure, i.e. the word *of* is what matters most, rather than the systems (or parts) that make up the system (of parts or systems) itself. We have explained this significance and provided a framework for identifying how, when, and why a system takes on one manifestation or another, and therefore provides an opportunity for managing the system appropriately.

Our perception that there exists a lack of inclination to shift the line of thinking among the engineering (and business communities) – and what can be done about this, i.e. to accomplish a paradigm shift, is grounded in the notion of complexity and how it applies to the different communities – engineering and complexity science.

The term complex derives from the Latin word *complexus* meaning to entwine. It's meaning today as an adjective is 'consisting of interconnected or interwoven parts.' As a noun it means 'a whole composed of interconnected or interwoven parts.' A complex really is a system. And being complex means being interconnected or interwoven, like for example a tapestry. The fact that the Bayeux tapestry is not really a tapestry, is probably incomplete and inaccurate, in addition to being anomalous, adds spice to what we have to say about complex, because we now understand complex to be replete in paradox.

The science of complexity is relatively new. A scintillating account of its origins, historical and technical, is provided by Mitchell Waldrup [1992]. A comparative newcomer to the science family it is nevertheless possible to demarcate phases in our understanding of complexity. The initial phase was occupied by understanding the forces of self-organization not realizing that self-organization was a 'system' in its own right e.g. Adam Smith [1759, 1776], Friedrich Engels [1884], Charles Darwin [1859], and Alan Turing [1950]. This was followed by seeing self-organization as a problem that transcended local disciplines and solving that problem, partially by comparing behavior in one area with that of another, e.g. comparing slime molds and ant colonies. We might well consider to have now entered a new phase which concerns the creation of self-organizing systems and the invention of artificial emergence: systems built with a conscious understanding of what emergence is, systems designed to exploit those laws, e.g. software that makes book recommendations on Amazon, does voice recognition on our cell phone, and finds mates over the Internet.

The entire process of complexity understanding is driven by the paradoxical theme of unraveling that which is interwoven in order to understand the parts, their interactions and their interweaving, whilst keeping it in its whole state since the unraveling will fail to produce the extraordinary emergent behaviors attributable solely to the existence of that whole and to that whole's properties which are meaningful only to it and remarkably different from properties attributable to the interwoven parts.

In summary, the paradoxes we have observed from our own studies and experiences of complexity include the following:

- complexity is much simpler than it first appears;
- simple things exhibit very complex behavior;
- little things mean a lot;
- myriad things are closer than we think;
- significant things are both vital and obscure;
- weak relationships bring strength and security;
- to those who have yet more shall be given and yet to those who have little even this will mean less; and
- perhaps the ultimate paradox, the reality that a complex is both a one and a many, simultaneously.

Therefore, our philosophy can be found in our treatments of the meaning of *of*, and in the reestablishment of the virtue of paradox as a pivot for shifting thinking [Boardman and Sauser, 2008]. In our treatment of *of* we try to establish the significant architectures that draw whole systems together in order to produce not simply emergence but an emergent culture, one that relies on emergence, the element of surprise, the risk of chaos, in order to produce new patterns of simplicity and elegance about which we could not know or foresee.

In our treatment of paradox we try to re-establish the significance of wisdom and where it might be found:

- in the multiplicity and simultaneity of viewpoints;
- in respect for competing perspectives;
- in the duality of the one and the many;

- in the conflict and the confusion that arises when we refuse to accept simple choices and with wisdom find a simplicity unforeseeable by mere resolution – something that is hidden and can only be found in the unthinkable.

So we conclude with these future challenges:

1. How can we design for and manage autonomy, belonging, diversity, connectivity, and emergence?
2. How do enterprises build project capabilities needed for SoS when managing paradox?
3. How do we learn about ‘best practices’ or attributes in the management of SoS?
4. How can we measure the breadth and depth of the capabilities of a SoS?
5. What frameworks can best explain the definition, initiation, planning, execution, and controlling of a SoS?
6. What kind of product life cycle models fit a SoS?
7. How does a system relate to the wider technological SoS in which they are embedded and vice versa?
8. How can the notion of network be applied to the levels of process and organization in a SoS?
9. Can we provide a context or system through which to interpret, define, and establish the boundaries of a SoS?

REFERENCES

- Anderson, P. W., 1972, More is Difficult, *Science*, Vol. 1777, No. 4047, pp. 393-396.
- Ashby, R., 1956, *Introduction to Cybernetics*, Chapman Hall, London.
- Bar-Yam, Y., 2004, "The Characteristics and Emerging Behaviors of System of Systems," NECSI: Complex Physical, Biological and Social Systems Project, pp. 1-16.
- Beer, S., 1966, *Decision and Control: The Meaning of Operational Research and Management Cybernetics*, Wiley & Sons, New York.
- Bernard, C., 1952, *Introduction a la Medecine Experimentale*, Flammarion, Paris.
- Boardman, J., Pallas, S., Sauser, B. J. and Verma, D., 2006, "Report on System of Systems Engineering," Final Report for the Office of Secretary of Defense, Stevens Institute of Technology, Hoboken, NJ.
- Boardman, J. and Sauser, B., 2006, *System of Systems: The Meaning of of*, IEEE International System of Systems Conference, pp.
- Boardman, J. and Sauser, B., 2008, *Systems Thinking: Coping with 21st Century Problems*, CRC Press/Taylor & Francis Group, Boca Raton.
- Brown, S. L. and Eisenhardt, K. M., 1998, *Competing on the Edge: Strategy as Structured Chaos*, Harvard Business School, Boston.
- Cameron, K. S. and Quinn, R. E., 1988, "Organizational paradox and transformation.," *Paradox and transformation: Toward a theory of change in organization and management*, Quinn, R. E. and Cameron, K. S. (Ed.), Ballinger, Cambridge, MA, pp. 12-18.
- Carlock, P. G. and Fenton, R. E., 2001, *System of systems (SoS) enterprise systems engineering for information-intensive organizations*, *Systems Engineering*, Vol. 4, No. 4, pp. 242.
- Commission, N. Y. T. C. T. L., 2007, "Current Medallions – sorted by TLC Medallion Number," *current_medallions.xls* (Ed.), TLC.
- Commission, T. N. Y. C. T. a. L., 2007, "About TLC," Vol. 2007.
- Consulting, S., 2004b, "NYC Taxicab Fact Book."
- Consulting, S., 2006, "The New York City Taxicab Fact Bok ", pp. 2.

- Consulting, S., 2006, "The New York City Taxicab Fact Book," pp. 60.
- Consulting, S., 2006, "The New York City Taxicab Fact Book," pp. 41.
- Consulting, S., 2006, "The New York City Taxicab Fact Book," pp. 1.
- Consulting, S., 2006, "NYC Taxicab Fact Book," pp. 37.
- Consulting, S., 2006, "NYC Taxicab Fact Book," pp. 55.
- Consulting, S., 2006, "NYC Taxicab Fact Book," pp. 25.
- Consulting, S., 2006, "NYC Taxicab Fact Book," pp. 44.
- Consulting, S., 2006, "NYC Taxicab Fact Book," pp. 42.
- Consulting, S., 2006, "NYC Taxicab Fact Book," pp. 43.
- Consulting, S., 2006, "NYC Taxicab Fact Book," pp. 29.
- Consulting, S., 2006, "NYC Taxicab Fact Book," pp. 35.
- Consulting, S., 2006, "NYC Taxicab Fact Book," pp. 13.
- Consulting, S., 2006, "NYC Taxicab Fact Book," pp. 12.
- Consulting, S., 2006, "NYC Taxicab Fact Book," pp. 31.
- Consulting, S., 2006, "NYC Taxicab Fact Book," pp. 57.
- Darwin, C., 1859, *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life*, John Murray, London.
- Davies, A. and Brady, T., 1998, Policies for Complex Product System, *Futures*, Vol. 30, No. 4, pp. 293-304.
- DeLaurentis, D., 2005, Understanding Transportation as a System of Systems Design Problem, 43rd AIAA Aerospace Sciences Meeting, pp.
- Engels, F., 1884, *The Origin of the Family Private Property, and the State*.
- Florice, S. and Miller, R., 2001, Strategizing for anticipating risks and turbulence in large-scale engineering projects, *International Journal of Project Management*, Vol. 19, pp. 445-455.
- Ford, J. D. and Ford, L. W., 1994, Logics of identity, contradiction, and attraction in change, *Academy of Management Review*, Vol. 19, pp. 756-795.
- Friedman, T. L., 2006, *The World is Flat: A Brief History of the Twenty-First Century*, Farrar, Straus and Giroux, New York.
- G.P.O., U. S., 1989, "Restructuring of the Strategic Defense Initiative (SDI) Program," Services, U. S. C. S. C. o. A. (Ed.), United States Congress. , pp. 16.
- Glass, N., 1996, Chaos, Non-Linear Systems and Day-to-Day Management, *European Management Journal*, Vol. 14, No. 1, pp. 98-106.
- Handy, C., 1994, *The age of paradox*, Harvard Business School, Cambridge, MA.
- Hobday, M., Rush, H. and Tidd, J., 2000, Innovation in Complex Products and System, *Research Policy*, Vol. 29, No. 7-8, pp. 793-804.
- Hofstadter, D. R., 1979, *Godel, Escher, Bach: An eternal golden braid*, Norton, New York.
- INCOSE 2006, (Ed.), Vol. 3, *INCOSE Systems Engineering Handbook*, INCOSE.
- ISO/IEC 2002, (Ed.), Vol. ISO/IEC-15288, *Systems engineering - systems life cycle process*.
- Jones, K. C., 2007, "New York Cabbies May Strike Over GPS Tracking " *InformationWeek* Vol. July 25, 2007.
- Keating, C., Rogers, R., Unal, R., Dryer, D., Sousa-Poza, A., Safford, R., Peterson, W. and Rabadi, G., 2003, System of systems engineering, *EMJ - Engineering Management Journal*, Vol. 15, No. 3, pp. 36.
- Kimmel, L., 1998, "Lord Nelson and Sea Power," <http://www.geocities.com/Athens/3682/nelsonsea.html>.
- Koestler, A., 1990, *The Ghost in the Machine*, Penguin, London.
- Kusiak, A. and Larson, N., 1999, "Concurrent Engineering," *Handbook of Systems Engineering and Management*, Sage, A. P. and Rouse, W. R. (Ed.), Wiley & Sons, New York, pp. 327-370.
- Lewis, M. W., 2000, Exploring Paradox: Toward a More Comprehensive Guide, *Academy of Management Review*, Vol. 25, No. 4, pp. 760-776.
- Maier, M., 1998, Architecting Principles for System-of-Systems, *Systems Engineering*, Vol. 1, No. 4, pp. 267-284.
- Mayor, N. O. o. t., 2007, "Mayor Bloomberg Announces Taxi Fleet to be Fully Hybrid by 2012 ".
- Miller, R. and Lessard, D. R., 2000, *The Strategic Management of Large Engineering Projects*, MIT Press, Boston.
- Nightingale, P., 1998, A cognitive model of innovation, *Research Policy*, Vol. 27, pp. 689-709.
- Panel, N. T. T., 2004, "New York City Transit Transportation Panel Survey."

- Parth, F. R., 1998, *Systems Engineering Drivers in Defense and in Commercial Practice*, Systems Engineering, Vol. 1, pp. 82-89.
- PMI 2004, (Ed.), *Guide to the Project Management Body of Knowledge (PMBOK)*, Project Management Institute, Newtown Square, PA.
- Press, T. A., 1998, "New York cabbies stage boycott over tougher rules," U.S. News
- Sage, A. and Cuppan, C. D., 2001, *On the Systems Engineering and Management of Systems of Systems and Federations of Systems*, Information, Knowledge, Systems Management, Vol. 2, pp. 325-345.
- Sage, A. and Rouse, W. B., 2008, "An Introduction to Systems Engineering and Systems Management," *Handbook of Systems Engineering and Management*, Sage, A. and Rouse, W. B. (Ed.), Wiley & Sons, Hoboken, NJ.
- Sauser, B. J. and Boardman, J., 2007, *Taking Hold of System of Systems Management*, Engineering Management Journal, Vol. forthcoming, pp.
- Sauser, B. J. and Boardman, J. T., 2007, *Complementarity: In Search of the Biology of Systems*, IEEE International Conference on Systems of Systems Engineering, IEEE, pp.
- Schaller, B., 2006, "Entry Controls in Taxi Regulation: Regulatory Policy Implications of U.S. and Canadian Experience," pp. 1-17.
- Schneider, K. J., 1990, *The paradoxical self: Toward an understanding of our contradictory nature*, Insight Books, New York.
- Shenhar, A. J., 1998, *From Theory to Practice: Toward a Typology of Project Management Style*, IEEE Transactions on Engineering Management, Vol. 45, No. 1, pp. 33-47.
- Shenhar, A. J. and Dvir, D., 2007, *Reinventing Project Management: The Diamond Approach to Successful Growth and Innovation*, Harvard Business School, Boston.
- Shenhar, A. J. and Sauser, B. J., 2008, "Systems Engineering Management: The Multidisciplinary Discipline," *Handbook of Systems Engineering and Management*, Sage, A. P. and Rouse, W. R. (Ed.), Wiley & Sons, Hoboken, NJ, pp. 113-136.
- Simon, H. A., 1996, *The Sciences of the Artificial*, MIT Press, Cambridge.
- Smith, A., 1759, *The Theory of Moral Sentiments*, Library of Economics and Liberty.
- Smith, A., 1776, *An Inquiry into the Nature and Causes of the Wealth of Nations*, MetaLibri Digital Library.
- Smuts, J., 1926, *Holism and Evolution*, Macmillan, London.
- Space, T. D. T. f. P., 2007, "The Design Trust for Public Space."
- Stenbit, J. P., Wells, L. and Alberts, D. S., 2003, *Complexity Theory and Network Centric Warfare*, DoD Command and Control Research Program.
- TLC, 2007, "Monthly Medallion Sales - Average Prices & Number of Transfers."
- TLC, 2007, "Saturn Vue and Toyota Camry Hybrids Join List of Approved Taxicab Models."
- Turing, A. M., 1950, *Computing machinery and intelligence*, Mind, Vol. 59, pp. 433-460.
- Waldrop, M., 1992, *Complexity: The Emerging Science at the Edge of Order and Chaos*, Simon & Schuster, New York.
- York, F. f. t. C. o. N., 2007, "New York Taxi Workers' Alliance."