

Strategies for Competition Beyond Open Architecture (OA): Acquisition at the Edge of Chaos

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Contributors:

Dr. Niraj Srivastava – Primary

Mr. Michael L. Rice

Dr. David Kwak

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2000 El Segundo Blvd.
P.O. Box 902
El Segundo, California 90245-0902**

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PRIMARY CONTRIBUTOR		CONTRIBUTOR		CONTRIBUTOR	
Name:	Dr. Niraj Srivastava	Name:	Mr. Michael L. Rice	Name:	Dr. David Kwak
Address:	Raytheon Company 1001 Boston Post Road East Marlborough, MA 01752	Address:	R2E, Inc. 2004 Victoria Dr. Stafford, VA 22554	Address:	Raytheon Company 1001 Boston Post Road East Marlborough, MA 01752
Phone:	202.904.2181	Phone:	540.720.0454	Phone:	978.930.3627
Email:	niraj.srivastava@raytheon.com	Email:	mrice.r2einc@verizon.net	Email:	david.kwak@raytheon.com

Raytheon Web Site: www.raytheon.com

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ABSTRACT

Department of Defense (DoD) Open Systems Architecture (OSA) policies are supposed to enhance acquisition reform to ensure competition for better pricing as dictated by the Weapons Systems Acquisition Reform Act of 2009. However, the competition for better pricing using OSA does not necessarily drive innovation that addresses increasing system complexity. In the face of increasing system complexity, uncertain security profiles, and a challenging budget environment, the defense acquisition process and SE efforts need to work in concert to produce defense systems that reduce time to deployment and are more adaptable. We look to complex adaptive systems (CAS) and evolutionary theory for strategies for competition using methods from dynamical systems and population genetics. The key insight of evolutionary theory is that many behaviors involve the interaction of multiple entities in a population, and the success of any one of these entities depends on how its behavior interacts with that of others. Furthermore, we investigate potential for bidirectional coupling between population density (market size) and the evolution of an emergent trait such as competition. We propose the use of the Component Competition Readiness Level (CCRL) metrics which define and measure competition readiness to promote agility in the complex dynamics of the acquisition processes.

INTRODUCTION

“If you want to build a ship don’t herd people together to collect wood and don’t assign them tasks and work, but rather teach them to long for the endless immensity of the sea.” —Antoine de Saint-Exupery, Wisdom of the Sands

In the last couple of decades the nature of the threat faced by our nation has changed dramatically. A Booz Allen Hamilton report¹ points out that the United States is increasingly facing threats that are surmountable, but that are highly unpredictable. The unpredictable, asymmetrical nature of the threats coupled with the accelerated pace of change in the security landscape—such as new and emerging foreign powers, non-state actors (**Figure 1**) with increasingly destructive enabling technologies²—are generating pressures on the way in which the DoD fields defense systems.

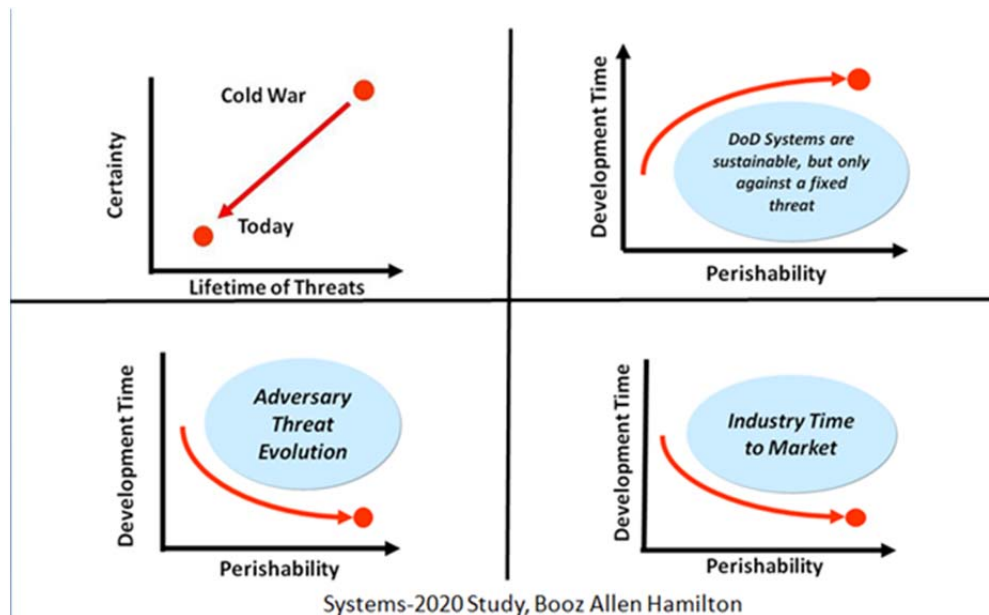


Figure 1. Transformative Forces in the DoD Acquisition Landscape¹

The DoD finds itself operating in a world that has become increasingly more complex and unpredictable³ while shifting “to a smaller, leaner force that is agile, flexible, and ready to deploy quickly”⁴ with “strategic agility.”⁵ These transformative forces have led to studies such as the System 2020¹ initiative and the National Defense Industrial Association (NDIA) *Final Report of the Model Based Engineering (MBE) Subcommittee*.⁶ The studies highlight the need for a SE transformation that could enable the DoD “to design and build an entirely new class of adaptive systems that allow the Department to operate with far greater speed and agility.”¹ The same trends are highlighted in the context of information technology (**Figure 2**), which provides as much as 80 percent of weapon system functionality.

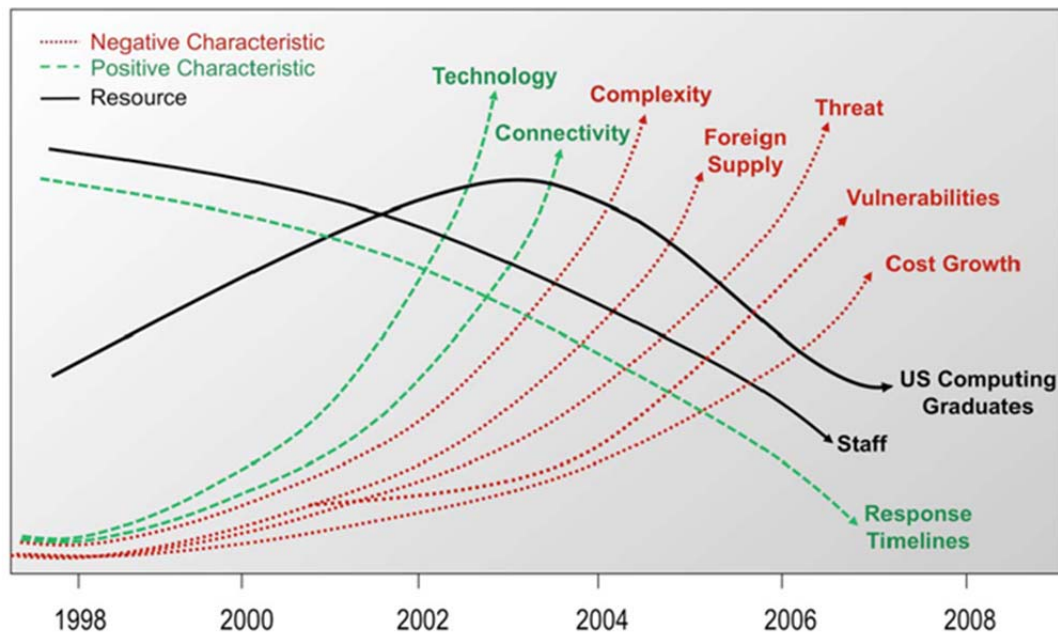


Figure 2. The Perfect IT Storm—“Rate of Technology Change Is Increasing as is the Interconnected Nature of Systems While Timelines are Shrinking.”⁷

The current response to a more complex and unpredictable world has been to field more complex defense systems. Many studies^{1,8} have documented the increasing complexity of defense systems (**Figure 3**). However, the increase in complexity has produced an increase in risk for system development such that the time to field and the cost of new systems are not acceptable. Traditional SE processes such as MIL-STD-499A are unable to deal with the N^m growth in system complexity, where N represents components and m is the interactions between components. The traditional system integration approaches are unable to deal with the power-law growth curve (just imagine doing first order testing on N components with m connections, not to mention second-order effects).

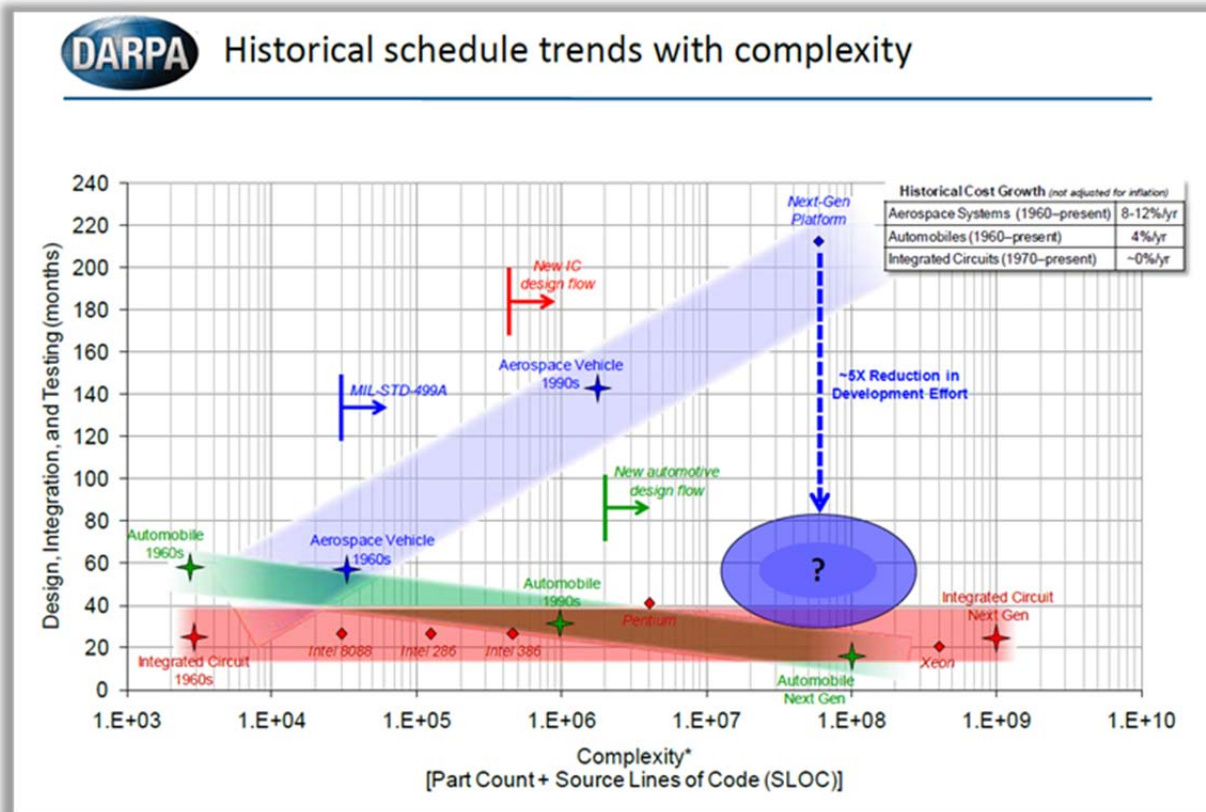


Figure 3. Variability in the Way Different Industries Have Managed Growth in Complexity.⁹

The System 2020 study, mentioned earlier, has proposed many system engineering (SE) approaches such as MBE, Platform Based Engineering (PBE), and Capability on Demand (COD) to modernize the discipline. The key insight of the System 2020 study is to leverage modularity and reusability to produce agility and adaptability.

The increasing complexity of defense systems has also contributed to the cost of defense system acquisition. In response, Congress passed the Weapon Systems Acquisition Reform Act of 2009 with the stated goal to ensure competition for better pricing. The DoD acquisition community has also been driving policy reforms for better buying power through open architecture.

The purpose of this paper is not to propose another SE approach. We derive insights based on our understanding of complex systems and social networks for a marketplace driven by competition that can adapt to produce cost-effective defense systems and that is able to evolve with new emerging threats.

BACKGROUND

The Under Secretary of Defense for Acquisition, Technology, and Logistics (USD AT&L), Honorable Frank Kendall, introduced Better Buying Power (BBP) 2.0 in his memorandum of November 13, 2013, to acquisition professionals across the DoD.¹⁰ BBP (<http://bbp.dau.mil/>) is now part of the DoD's mandate to do more without more by implementing best practices in acquisition. That memorandum was subsequently followed by another on April 24, 2013, which provided the implementation directive for BBP 2.0.¹¹ The latest BBP direction comes nearly

three years after the initial BBP 1.0. In both cases the intent, as expressed by USD AT&L, is to obtain greater efficiency and productivity in defense spending by pursuing an initial set of initiatives in five areas. With the issuance of the latest BBP 2.0 directive, BBP identifies seven areas of focus that group a set of 36 initiatives to drive affordability in defense procurement and improve defense industry productivity. One of the directives promoting competition includes enforcement for OSA and management of technical data rights to strengthen the Defense Department's buying power, improve industry productivity, and provide affordable, value-added military capability to the warfighter.

OSA incorporation into Area 5, "Promoting effective competition," represents a milestone unto the topic itself. Competition is considered by Defense leadership as the single most powerful tool available to the Department to drive productivity. For products, acquisition strategies must address how program managers will realize and maximize competition from program inception through sustainment.

OSA merges technical architecture with an open business model. Technical architecture defines open standards, published key interfaces, and full design disclosure to produce modular, loosely coupled but highly cohesive systems. Recent efforts such as UAS Control Segment (UCS) Architecture, The Open Group Future Airborne Capability Environment (FACE™), OMS, and Acoustic Rapid Commercial-off-the-shelf (COTS) Insertion (ARCI) are all designed to support OSA. However, promoting effective competition also requires an open business model.

Independent of BBP, the DoD OSA policies and governance, over the past several years, have significantly impacted the acquiring of weapon system products and processes. In reviewing past actions and accomplishments, the discussion must be viewed from both an acquisition and post-IOC (deployment) context. From the acquisition systems engineering perspective, based on the utilization of broad-sweeping Modular Open Systems Architecture (MOSA)/Naval Open Architecture (NOA) principles, one could state that DoD stakeholders have achieved an excellent rating of "A+." However, from a post-deployment context perspective, whereby the Government can fully receive fiscal relief due to competition, the rating at best is "fair/poor." So, why is the Government unable to receive high levels of return on investment (ROI) once a system is deployed? To address this complex subject, numerous factors must be addressed, some of which are listed below:

- Cultural behavior is a significant contributor. If a priority scheme were established to assess which MOSA/NOA principles are important, real competition at the deployment phase would rank the lowest. Mission performance, acquisition cost, and schedule are still the primary drivers that acquisition program managers adhere to.
- Industry has implemented OSA initiatives primarily from a corporate enterprise commonality and productivity perspective, such as build less, maximize reuse through portability, and therefore, sell more. OSA attributes can be used to gain market share locking-in such as corporate modularity, corporate selection of certain standards and corporate frameworks, and common product lines. These elements are all based on commercial COTS/open software products and processes. These attributes are often used to drive down operating costs and provide competitive pricing at major awards events.
- The DoD has difficulty aligning a data rights strategy with a SE maturity model. The end result is that the Government limits its success by its inability to fully measure what/when it owns, what rights it has, and how it should release this information in a time-based

manner to ensure that real competition at the component level will exist, especially during the operational and support (O&S) phase.

- The DoD lacks a measurable governance model for consistent and repeatable outcomes for competition based on OA. Tools such as the MOSA Program Assessment and Rating Tool (PART)/Open Architecture Assessment Tool (OAAT) are often ineffective since contractors always obtain passing grades due to the generic nature of OSA principles, and little to no emphasis is given to post-Initial Operations Capability (IOC) ROI.

The current tools sets do not consider the interaction of the technology with the environment in which they exist, namely the business environment. CCRL complements the Technology Readiness Level (TRL), a metric to assess technology maturity, with component-level metrics relating to integration, interoperability and program readiness for Component Competition.

As stated within the general guidance for Area 5, strategies to be considered include “OSA that enables competition for upgrades, acquisition of technical data packages, and competition at the subsystems level. At the Component level, the prospect of a development program for a substitute or follow-on product can create indirect competitive pressure.” It is within the realm of the “component level” decomposition that the associated business and technical consideration must be carefully and thoughtfully investigated. For an open and free competition among suppliers, the acquisition process needs to balance supplier community (size, available industry competency, persistent life for follow-on contract, etc.) and granularity of technical specification (architecture, interfaces, standards, etc.) with data rights and intellectual property.

It is the intent of the proposed CCRL to measure maturity levels of both the open business model and the technical architecture. The definitions of technical architecture have been well studied; however, metrics to define an open business model are more problematic. CCRL leverages concepts of social networks to answer or at least study open business model issues to measure the success of implementing OSA as part of promoting effective competition.

COMPLEX ADAPTIVE SYSTEMS

Insight to systems that consist of many interacting components and hierarchies lies in understanding complexity theory. SE approaches are necessary but not sufficient to deal with the complexity of modern weapon systems and respond to the changing needs of the warfighters. Over the last couple of decades, a body of work based on mathematics has led to the discipline of nonlinear dynamics and the study of complex adaptive systems. Complex adaptive systems is a new approach to science that studies how relationships between parts give rise to the collective behaviors of a system and how the system interacts and forms relationships with its environment.¹² The term *complex system* formally refers to a system of many parts which are coupled in a nonlinear fashion. Natural complex systems are modeled using the mathematical techniques of dynamical systems, which include differential equations, difference equations, and maps.¹³ The insight is that behavior of the complex system is influenced by

- Interconnectedness with the environment and itself
- Nonlinearity of coupling
- Applicability of the principle of superposition not valid
- Emergence of system properties and behaviors

The system behavior is said to be emergent when it cannot be understood simply as the sum of its constituent parts. Emergent behavior involves interactions between individual components

that yield distinct patterns at the system level. Emergent systems have group level outcomes that cannot be understood simply as the superposition of their constituent parts; instead, emergent group behavior is nonlinearly related to individual interactions. Moreover, just as individual actions affect group outcomes, group outcomes feedback to affect individual actions. This coupling between the microscopic individual level and the macroscopic group level makes the model of emergent behavior useful for understanding a dynamic marketplace driven by competition that leads to the emergence of innovation and productivity for DoD acquisition.

A key insight of complex adaptive systems has been an appreciation of the mechanism of emergence. Models of self-origination show how systems can locally adapt to a critical region in which the global properties of the system take on regular behavior, such as a power-law distribution of event sizes. Such ideas are likely to serve as fodder for explaining various social scaling laws, like the success and failure of open source software (OSS) projects.¹⁴

In a complex system, it is not possible to reduce the overall behavior of the system to a set of properties characterizing the individual components. Furthermore, interactions produce properties at the collective level that are simply not present when the components are considered individually. These types of complex systems, specifically CAS, have emergent collective behavior that can not be explained by sum of the constituent parts or by superposition principle. However, the evolutionary models to study emergent behavior provide fascinating insight into observed behavior in emergent social phenomena from the perspective of evolution by natural selection. Much of the analysis of the dynamics is focused on stable equilibria and their bifurcations. Random (stochastic) effects play a crucial role in the vicinity of bifurcation points in a decision tree. In complexity theory, bifurcation of new branches of solution following the instability of the current state caused by nonlinearities and interaction with the human system generates a source of innovation and diversification. This endows the system with new solutions.

The CAS approach considers landscapes (of possible solution) in which the various elements interact in nonlinear ways, resulting in a solution space with many peaks and valleys where each peak represents a solution branch on the bifurcation curve (**Figure 4**). Contribution of complex adaptive social systems has been recognized for the nonlinearities and interactions that lead to a search across these peaks and valleys for a collective decision-making dynamic.¹⁵

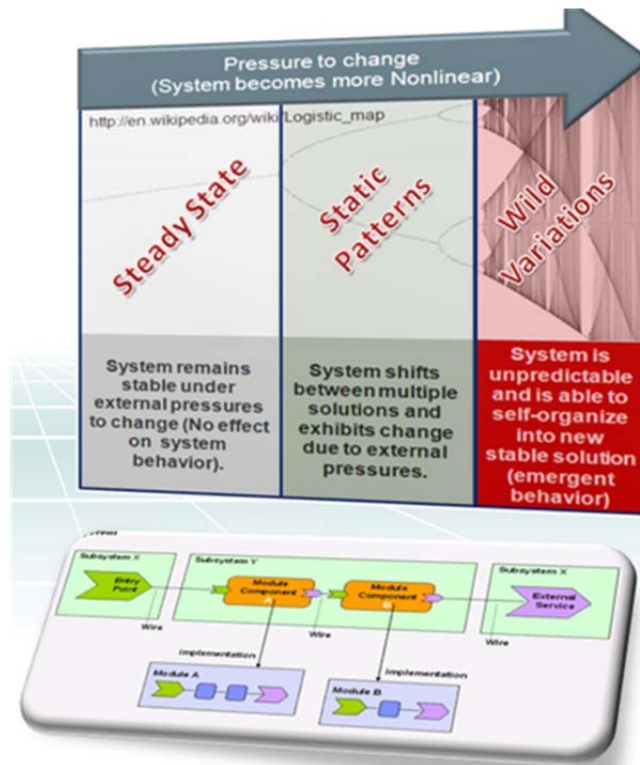


Figure 4. Bifurcation Generates New Decision Points and Leads to Complexity but Also Can Serve as Source of Innovation

Social Network and Evolutionary Dynamics

A suitable language to relate emergence in CAS to the dynamic DoD acquisition and procurement marketplace is found in the study of the evolutionary dynamics of behavior in social networks.¹⁶ Our main thesis is that institutions such as the DoD serve to build a network of actors, with individual actions, into a marketplace with desired emergent behavior. The notion of institutionalization can be a set of rules, conventions, or mechanisms that produce a pattern of aggregate behavior.

The description of the marketplace is thus reduced to a network, and a network is any collection of entities in which some pairs are connected by links, as shown in **Figure 5**.

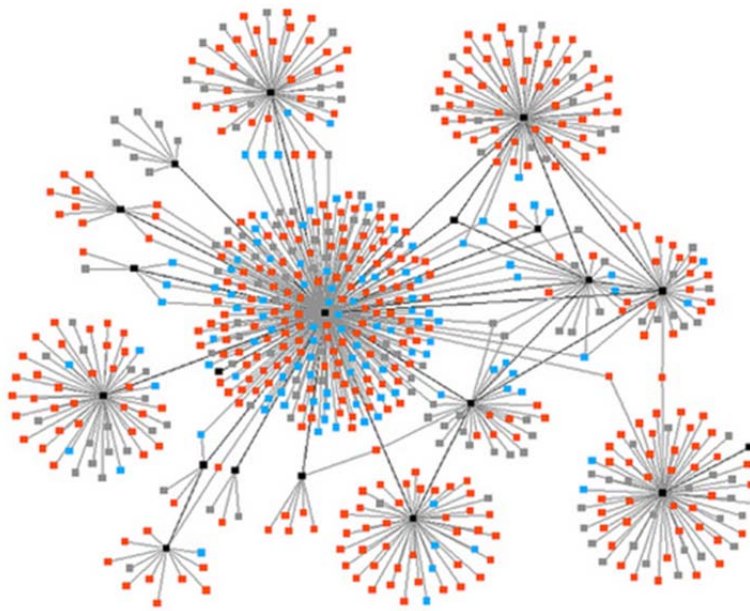


Figure 5. A Graph Is Formed by Vertices and Edges Connecting the Vertices.

Connectedness can lead to very complex networks.

The study of these networks provides key insight for institutional design to produce a self-regulating marketplace with desired results. Depending on the properties of the network, such as the total number of links connected to a node, a network can exhibit a range of behavior—from a very rigid or static network to a chaotic network where changing a node or a link completely alters future dynamics of the network. However, some networks also settle into relatively few patterns of behavior or self-organized criticality. Such critical states with long-range order and independent of initial conditions are said to be “on the edge of chaos.” These systems are also adaptive such that a change in the environment causes perturbations to the system; however, the systems reorganize themselves with most of the previous characteristics. A network’s behavior is dependent on the network topology. The following properties are generally used to characterize networks:

- **Degree distribution** – the degree of a node, k , is the total number of links connected to this node, and degree distribution is the relative frequency of each value of k in a network.
- **Diameter** – maximum number of links traversed for communication to flow from one node to another by following the shortest route possible
- **Cluster** – set of all nodes connected by some path
- **Clustering coefficient** – of a node is the ratio of the number of links to the total number of possible links. Clustering coefficient of a network is the average of all clustering coefficient of the nodes.

Studies show network structures with a high cluster coefficient and a small network diameter are found in a wide range of natural, social, or collaborative networks.¹⁷ These networks are called scale-free networks. The degree distributions for these networks follow a power law, as in complexity theory. The robustness properties of scale-free networks are important for the BBP marketplace (open business model) because information and resources can easily and quickly

diffuse through the network even as nodes continuously join and leave the network (under contract/out of contract). In addition, scale-free networks are robust against node failures and preserve its structure.

A look at social networks provides us with insight for deriving the CCRL metrics for open business models to supplement existing measures of technical architecture.

Open Source Software (OSS) Development Community

Multiple case studies have looked at OSS development projects and network structure of the open source community.¹⁷ Conventional wisdom is that open source development produces more bug-free code, is faster, and is more innovative and responsive to the user needs. OSS projects are self-organized and employ rapid code evolution, massive peer code review, and rapid releases of prototype code.¹⁷

OSA should look to replicate the positive aspects of OSS by moving to an open system architecture paradigm. Modular software architecture, common standards, and tools are necessary but not sufficient to explain the success of OSS. OSS communities also exhibit scale-free network features and have power-law distributions since communities are self-organizing due to sequential growth and preferential attachment (business ties, preferred supplier relation, etc.). OSS networks tend to have a small diameter and high clustering coefficient. The small distances result from the fact that a member can participate in multiple communities; furthermore, large numbers of members participate on one project clustered around a thought leader. An analysis of 39,000 open source projects hosted at SourceForge.net involving over 33,000 developers by researchers at University of Notre Dame shows that open source movement is not a random graph but displays preferential attachment of new nodes (developers joining projects). These networks display power-law relationships (shown in **Figure 6**) due to heavily skewed distributions which “typically happens under situations of positive feedback or increasing returns and is sometimes called the ‘rich-get-richer’ effect or the ‘band-wagon’ effect”.²² OSS communities are organized around more than just some common standards; they are driven by market dynamics due to self-selection of projects by developers and users. The self-selection drives some projects to grow disproportionately larger than predicted by random growth and leads to the power-law distribution. Alternatively as shown in Stony Brook University study that the age-old adage that “success breeds success” is a reality²³ even in the OSS community.

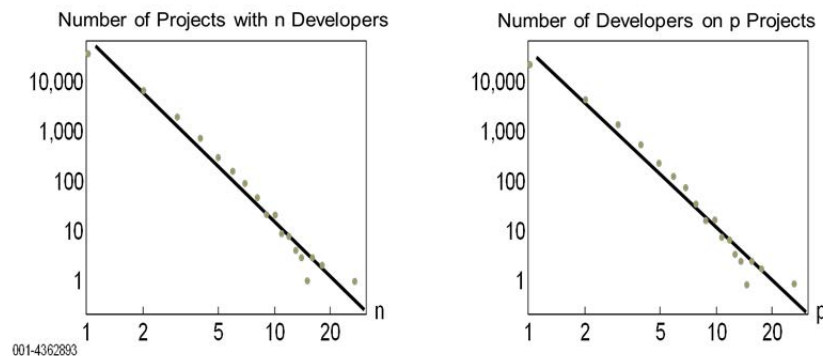


Figure 6. Power-Law Relationships: OSS Project Size and Developer Project Membership (Madey, Freeh, & Tynan, 2002)

A competitive DoD marketplace that is self-organizing, adaptive, and agile needs more than just OSA, but must also be engineered to support a dynamic open business model.

OPEN ACQUISITION MARKETPLACE (OAM)

A dynamic ecosystem that encourages component competition requires establishing a framework that depicts the confluence of business and technical drivers. Part of establishing a business ecosystem or a network that encourages component competition is to foster proper dynamics between the business (network architecture) and the technical framework.

An open and free competition among suppliers fosters forming a scale-free supplier network, as observed in the OSS development community.¹⁷ A strategically well-crafted platform ensures the creation of common architectural constructs and related automated tools to develop a system structure/platform that is based on commonality, as well as planned variability.¹ Platforms with well-defined standards for both structure and interfaces promote the characteristic of reusability. Without standards, reuse is minimized. Additionally, the structure and interface standardization can improve system developments. For example, satellite development can be improved by using standard interfaces for the sensors installed on the satellite bus. This allows for more adaptability within the system.¹ The adaptability is a key foundation for realizing capability on demand, which allows for dynamic composition of capabilities with standard structure/interfaces.

The Internet, the most successful open marketplace, has well-defined open standards and platforms, such as Internet Protocol Version 4 (IPv4) and associated Internet transport and application layer protocols. Especially, IPV4 became emergent as the waist (i.e., the passing tube) of the layered hourglass business/technical architecture, as shown in **Figure 7**. It managed to survive the intense competition with other similar protocols, including Novell's Internetwork Packet Exchange (IPX), the X.25 network protocol used in Frame Relay, the Asynchronous Transfer Mode (ATM) network layer signaling protocol, and several others.¹⁸ Then it became ossified, surviving much longer than most other protocols, while providing stability to the entire Internet ecosystem. Of course, there is no guarantee that IPV4 will stay forever. Evolutionary force has and will continue to evolve the Internet's layered hourglass architecture.

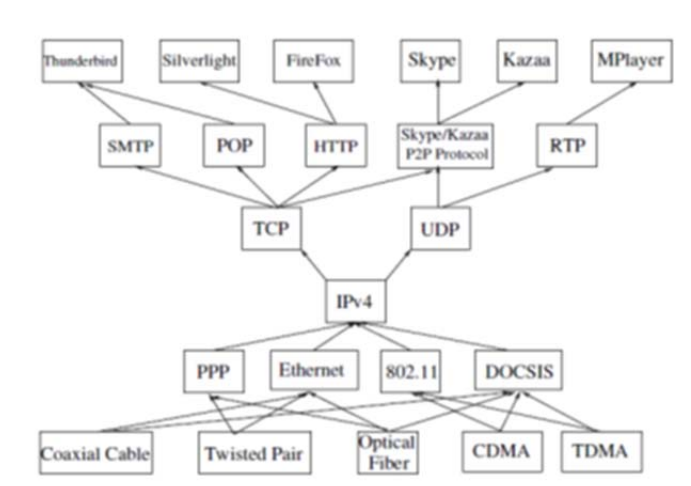


Figure 7. An (Incomplete) Illustration of the Hourglass Internet (Akhshabi & Dovrolis, 2011)

One of the notable characteristics of the architecture is that the lower part of the hourglass is significantly smaller than the upper part.¹⁹ This is an emergent property. In retrospect, it is

plainly obvious too. Richer opportunities exist at high layers, where applications and services' market flourish, than the lower layers, which mainly deal with links and physical layers. The well-defined IPV4 spurred numerous suppliers who produced Internet-based services and applications, and eventually made a key contribution to the creation of a totally new and highly diversified and agile Internet applications/services industry. One of the keys to the huge success of IPV4 is that it was neither too restrictive to discourage new entries, nor too permissive to create incompatible products and services.

Our goal is to recreate the paradigm of the layered Internet hourglass architecture in the DoD acquisition market, called Open Acquisition Marketplace (OAM). Again, the role of the waist of the OAM is paramount. Our current conjecture is that open architecture (OA), common platform, and standards are excellent candidates for forming the waist (i.e., the tunnel tube) of the OAM hourglass architecture. However, there is a small difference between the Internet layered hourglass architecture and the layered defense OAM. DoD cannot wait indefinitely until a proper waist standard is emergent.

Additionally, most commercial products don't support an infrastructure that has a product life of 20–40 years, therefore, comparing Android apps with longer term DoD apps has product sustainment limitations. Therefore, the DoD's OAM must be driven from a low-volume, long-term product cycle-life affordability driven perspective.

Given the low volume, the DoD is seeking to create a DoD enterprise-driven marketplace whereby competing organizations can buy and sell their state-of-the-art products. However, too many choices, too many variations of the infrastructure could dramatically impact the success of component competition and defeat the ability to drive down costs. Our layered OAM must offer some levels of stability to withstand turmoil at the other layers.

New challenges will emerge regarding infrastructure not so much from a research, development, test, and evaluation (RDT&E) view but from a long-term sustainment objective. The emerging role of the Government will change from a capability-driven organization to include component competition as a transactional role-based monitor.

Carefully devised platforms, open standards, and data rights are the key parameters for success. Standards and data rights need to be exercised at key locations in the hourglass to maximize interoperability and drive innovation. A choice of platform and standards directly contributes to lowering the barrier of entries and fostering competition among suppliers. This rationale warrants the Government (or a consortium composed of Government and industry partners) to take adequate ownership (or at least, a critical leadership) of crafting and/or selecting a platform and standards. It is not necessary to "peanut butter" OA and data rights to the entire solution stack. Not only is it unnecessary, but it may be detrimental to a healthy business ecosystem.

Recent efforts such as UAS Control Segment (UCS) Architecture, The Open Group FACE, OMS, and ARCI are all designed to support OA, which is well aligned to support the aforementioned OAM. The remaining question is how well these OA standards are actually performing in the context of the OAM, while creating a desirable waist effect in the layered hourglass OAM architecture, as shown in **Figure 8**. A piloting effort in an actual program context is proposed in the context of a real acquisition program.

Open Acquisition Marketplace (OAM)

- Measurable robust supplier network (i.e., scale-free supplier network)
- Adequate incentives and alignment to promote good behavior
- Assurance suppliers are not locked-in
- Aligned with platform-based product family development
 - Layered Bowtie/hourglass architecture
- Alignment of Data Right Strategy (DRS) with open architecture Component Competition strategy.
- V&V for transparency

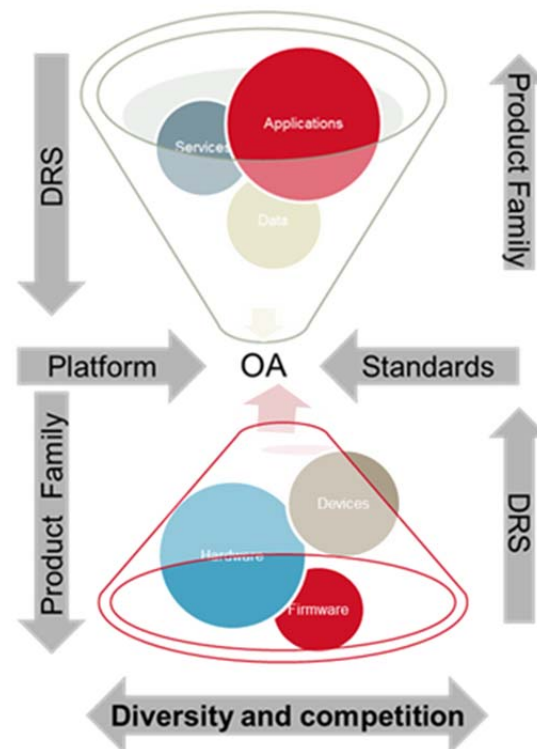


Figure 8. OAM in a Construct of Layered Hourglass Architecture

Product Line Architecture (PLA) has not been well utilized by the DoD¹. PLAs enable acceleration of delivery of technical capabilities to win an unpredictable, asymmetrical war; to prepare for an uncertain future; and to reduce the cost, acquisition time, and risk of major defense acquisition programs¹. PLAs are open architecture with published, accepted interfaces to components that can be provided by different vendors. Thus, PLA naturally encourages new entries of suppliers, and creates an open and fair competition among suppliers.

Properly aligned Data Right Strategy (DRS) with the above open architecture component competition strategy ensures the creation of a purposeful OAM. Again, periodic verification and validations (V&Vs) on the framework discussed above should provide greater confidence that the systems' open architecture is on the right track with regard to promoting a component competition ecosystem.

COMPONENT COMPETITION READINESS LEVEL (CCRL)²⁴

CCRL is concerned with documentation and dissemination program roadmaps to drive an open acquisition process in the OAM, to provide the infrastructure and organization for system integration. MIL-STD-881C Work Breakdown Structure (WBS) was used to provide a guide for defining the top three levels as shown in **Figure 9**. The levels are as follows:

- Level 0: Goal
 - Reduce total ownership cost through agility and adaptability
- Level 1: Drivers

- Technical drivers were addressed through Open Infrastructure and Roadmaps
- Business drivers were addressed through Open Acquisition and Organization
- Level 2: Measurable Objectives
 - Inter-relationship of objectives that generate a complex dynamic behavior resulting in competition

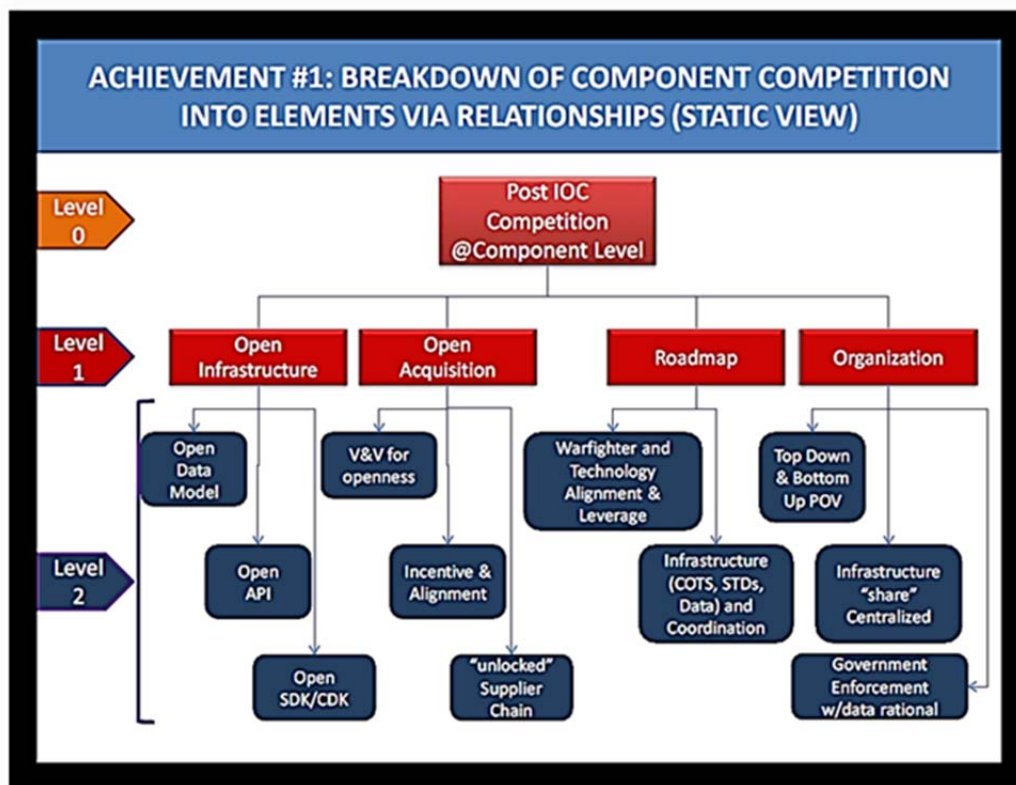


Figure 9. Achieving Competition at Component Level Requires a Balanced Interplay of Business and Technology in OAM

Level 1: Open Infrastructure Composition

Open infrastructure requires the involvement of numerous stakeholders that drive the development of Interface Technology Requirements via three measurable objectives:

- Common Data Models
- Open Application Programming Interface (API)
- Open Software Development Kits/Component Development Kits (SDK/CDK)

Level 2 defines and codifies Interface Technology Requirements that include all components (the application layer, transport layer, network layer, data layer, and the physical layer) and provide for a Protocol Requirements and Performance Requirements. Included in the Interface Technology Requirements are the open infrastructure tasks for promoting a component competition ecosystem and periodic third party evaluations and assessments to judge the openness of the infrastructure. In this technical framework infrastructure, openness is not as much a determination of whether the technology is an industry standard, de facto standard, etc.,

but it is more whether or not the technology is available to all of the organizations that want to compete and contribute modules to the program system.

Along with the SDK/CDK and its associated middleware, key components and their key interfaces should be identified. These components and interfaces are the ones that implement the feature/functionality upgrades in the aforementioned system capabilities roadmap. By designating these components and interfaces as key, they require more extensive documentation and stewardship throughout the program execution. The key components, standards, and interfaces should be identified during the system architecture design phase and maintained for the remainder of the program execution.

Relying on all of the organizations contributing to a program to integrate their modules into the greater system without a designated program test bed is a management headache. Therefore, it is important for the program to have an integration test bed with which all contributing teams integrate their components. Otherwise, integration efforts will be too disjointed to be effective.

Finally, a third party assessment team should review the technical framework infrastructure periodically to fulfill the V&V phase. An assessment should provide greater confidence that the systems' open architecture is on the right track with regard to promoting a component competition ecosystem.

Open Infrastructure Composition: Common Data Model

Anyone who has designed, developed, and integrated a sensor processing system has encountered the challenge of matching data structures and data types. Writing data schema translators as part of component and external interfaces is not a scalable or feasible solution. This is especially true of network-centric, distributed sensor processing systems. In these systems it is important for all of the participants to understand and agree upon what types of data are being processed in the system, where in the system the data needs to be, and how it will get from one node to another in the distributed system. The appropriate solution is to develop a common data model that spans the system and ideally is compatible with the data model across the enterprise. The data model should be developed before Preliminary Design Review (PDR), and it should be revised as needed past IOC.

Aligning data right strategy with data model elements is considered essential. There are two objectives, interoperability and ownership. If the Government is going to provide affordability benefits through sharing, then the terms and conditions associated with the shades of ownership and data content must be discussed as a team-driven event—legal (Intellectual Property [IP]/Acquisition); engineering (Architecture/Subject Matter Experts); managers (Program/Product IPT/ Supplier Chain), and contracts.

Open Infrastructure Composition: Open API

Given that a weapon system contains many sub-components, cards, and integrated chips, it is essential that the Government develops a methodology to select wisely only those APIs that they consider to be protected for competitiveness. Therefore, based on the successful identification of key components, comes the ability to identify corresponding key interfaces (software and hardware). The word *key* in a generic term, however, from a MOSA context key interfaces are those interfaces that are related to components that are changing often and are costly to change.

The word *open* in open in MOSA needs to be redefined with respect to competition and not tagged with the loosely used term such as widely-used published standards. In this context of competition, APIs are considered to have the following attributes:

- Complete and accurate with deviation fully disclosed
 - MS-C maturity—contains any last minute changes due to test and evaluation activities
 - Updated documentation such as ICD, IDD, etc.
- Management and sustainment—adaptability, agility at the API
 - API modification and patching
 - Tools and processes

Open Infrastructure Composition: Open SDK/CDK

In the past, SDKs have been well known and understood to be critical enablers in support of a modular interface driven system approach. The discussion as to whether the DoD needs to construct, manage, and govern CDKs is pending. The CDK context is driven from a modular application perspective with tools and processes to enable others to upgrade components via periodic functional upgrades, similar in nature with apps upgrades. Not all competition will require CDKs. It depends on the Component Competition roadmaps and associated strategy. The amount of agility will dictate the need for CDKs. If the component has an agile evolution-based upgrades strategy with constant modifications to the baseline components on a periodic duty cycle, then CDKs might be desired. If the component upgrade path supports both evolution and major upgrades (disturbing innovation) making previous components obsolete, then CDKs may not be the best option.

The CDK will emerge as a key element to the success of DoD component competition. CDK can be used to create a complete and functional model, define its functional requirements API and level of abstraction, define the components, and define all the input/output (I/O) (pins) which are made visible to other components. CDK must/will contain the following items, but not limited to

- System/Model Driven Items
 - Hands on Lab (HOL) and Executable Code
 - Target Description, compilers, memory processors, networks, etc.
 - Functional and System Description Tools
- Component Based Horizontal and Vertical Integration (Real Time [RT]) Requirements
 - Latency and Hard/Soft/Best Effort RT requirements

A key part of a program SDK to CDK interface is the middleware. Middleware libraries are any library that abstracts away computational, communication, and/or task management of the underlying operating system and hardware from the algorithms and applications. To the greatest extent possible, all algorithms and applications for the program should only call the program middleware libraries; the algorithms and applications should not make direct operating system or hardware calls. This provides a more portable set of algorithms and applications. If a certain operation is not supported in the current program middleware, an appropriate middleware library should be integrated or developed so as to abstract that functionality from being called directly from the algorithm or application. The small performance impact of inserting a middleware call is more than offset by the portability that is afforded with the middleware. The SDK/CDK

includes the software libraries along with tutorial, documentation, etc. It could even include virtual machine builds in which algorithms and applications are developed. Work on the SDK/CDK should have started by the PDR, and a usable version should be available soon after the Critical Design Review (CDR).

Level 1: Open Acquisition Composition

The approach to acquire a DoD system that is built ground up for component competition, from a life cycle perspective, is considered essential. There are three primary business drivers enablers, considered Level 2 items: a) V&V for transparency, b) proper strategy to provide adequate incentives and alignment to promote good behavior of the willing and able, and c) assurance that after system deployment, certain suppliers are not locked in for the life of a program.

The acquisition strategy should be aligned with a modular product family design. The common functions (modules) for a given product platform have the governance to promote reuse across derivative products. Within a product family, a collaboration, communication, and continuous delivery mechanism is established to promote a robust network. Finally, a third party assessment team should review and assess the health of the ecosystem using metrics defined for scale-free networks.

Timing of events demands the alignment of DRS with that of the open architecture Component Competition strategy. Getting Government Purpose Rights (GPR) or Unlimited Rights or knowing what sub-elements have restricted rights must be transparent to all interested parties before major contract awards. If components are labeled incorrectly, the Government must take appropriate and timely steps to challenge such stated rights to ensure proper handling and markings.

In the open acquisition process, all efforts should be made to isolate all vendor-specific IP and technology in specific modules/components for a derivative product. The lock-in of suppliers from a long-term perspective often prohibits the Government and prime from selecting components from third parties. The prime/lead systems engineer (LSI) must address such issues before the Materiel Solution Analysis (MS-A) phase award. They must recognize this challenge and state upfront how they plan to ensure competition. Upon entering the Technology Development (TD) phase, the challenges will be understanding what and what not to open and compete. An item that has a great deal of agility (rapid number of changes having high cost) is best suited for competition.

Level 1: Roadmaps Composition

Most program managers are familiar with the technology roadmaps that are important to every program. Technology roadmaps are particularly important to maintaining component competition in programs and are instrumental for defining PLAs. Program managers and lead engineers must maintain cognizance of the technology trends in industry and be able to explain how those trends will impact the program. The PLA should be addressed soon after passing Milestone A (MS-A) and should be kept up to date with periodic updates well past IOC.

Along with the PLA, a system capabilities roadmap activity is equally important. Many technology-driven programs require that the system to be deployed has not only certain features at IOC, but also subsequent upgrades to the IOC system to address evolving threats. It is the roadmap of the IOC features and feature upgrades that is critical to managing the openness of the

system and the solution platform as a whole. The system capabilities roadmap should be developed and documented, and the product platform identified.

Level 1 Driver: Organization Composition

The prime/contractor organization must implement policy, processes, guidance, tools, and training. The processes shall outline an approach to implement the MOSA and NOA requirements system during product development. This area demands an organization to change based on three enablers, considered Level 2 items: a) top-down and bottoms-up alignment, b) infrastructure information and data models through a centralized process, and c) a greater enforcement role based on sound business-technical rationale.

CCR Assessments (CCRAs) are established with trained people to ensure that Government and Industry have successfully implemented MOSA and NOA principles. The frequency and level of assessments were taken into consideration leveraging both Face-to-Face (F2F) and WebEx assessments at key milestones in the systems acquisitions life cycle. The programs will schedule the CCRAs which will be conducted jointly with Government and Industry.

Building an organization for component competition (buying and selling) requires a work force that connects numerous actions in accordance with the product life-cycle process and not solely at the RDT&E phase.

Often a program manager will assign one or two individuals the task of managing OSA activities. This is done not from a design team perspective, but more from a systems engineering verification and validation process perspective—what is needed to pass a milestone decision authority? Therefore, the general workforce doesn't always fully understand nor grasp the inter-relationship and consequences of mistimed or non-existent actions.

These three sub-areas collectively drive an organization to embrace component competition. The outcome creates consistency and/or uniformity, a desired common workforce belief. The effects must be addressed from a top-down and bottoms-up enterprise initiative that offers vast productivity, behavioral, and, eventually, cultural benefits.

The Government must provide CCR training and certification, which will be made available to the project development team. If component competition is going to be a serious contender in the DoD's future business acquisition culture, then workforce training must be emphasized. The workforce must recognize the complexities of competition, act in a timely manner, and govern from a domain enterprise POV. This requires a series of inter-related training modules to ensure proper content and context. A series of trust-but-verify assessments (question-and-answer tests) must also be implemented. These tests should not be tailored from a "one-problem and one-solution" mentality but from an inter-relationship of WBS elements that produce complex business and technical effects. Given that our workforce is constantly rotating, the frequency of training needs to be conducted at every post-milestone decision award. For example, during a pre MS-A award, the team is usually small but experienced in the area of "business as usual." When program enters an EMD phase, the composition and numbers increase greatly and training must be reapplied. If not, components that were circled for competition at PDR can quickly become non-competitive during the EMD tasks due to untrained, unaware individuals.

Creating a centralized infrastructure that is shared by the greater community is a critical enabler for OAM that supports component reuse including buying, selling, or trading of new and modified components. The centralized infrastructure must also facilitate full disclosure at the interface and support data models for interoperability layers and disclosure of any hidden IP data

rights. Paying for components is based on third party stakeholders obtaining needed information to enable them to compete on equal footing. The process must be established based on fairness aimed at reducing so-called insider trading.

The CCRAs use personality bands (PBs), which are defined within the acquisition life cycle and are aligned with the Systems Engineering Technical Reviews (SETRs) and major milestones. The CCRAs consist of five F2F meetings to assess the personality band (PB2, PB4, PB6, PB7, and PB9) and three informal Web-Ex meetings (PB3, PB5, and PB8) to be held during the acquisition life cycle, as shown in the CCRA Groupings Chart and as listed in **Table 1** below.

Table 1. CCRA Assessment and Acquisition Life-Cycle Phase

Acquisition Life-Cycle Phase	Assessment Type	CCRA
Technical Maturity (TM)	F2F	PB2
TD	Web-Ex	PB3
TD	F2F	PB4
TD	Web-Ex	PB5
TD	F2F	PB6
EMD	F2F	PB7
EMD	Web-Ex	PB8
EMD	F2F	PB9

CCRL Implementation via an Acquisition-Systems Engineering Process

CCRL defines a process consisting of both a business and a technical framework strategy. As a business strategy the process evaluates the appropriateness and feasibility of applying scale-free networks to successfully permit component competition and third-party involvement. The CCRL process for development programs concentrates on life-cycle affordability and managing change as part of the overarching business strategy by decomposing products into functions, grouping common functional modules into a common product platform, and choosing standards for interfaces to facilitate addition, removal, and substitution of modules. Also of importance is prioritizing and identifying the subsystems/modules that change most often and therefore have the greatest impact on program cost over its life cycle. Using the Key Open Sub System (KOSS) the program can determine the subsystems, components, relative rate of change over the life cycle, cost of change, and relative value to the warfighter. The CCRL process provides guidance for the program to document the hardware and software open system architecture design requirements for the entire program development effort including the TM (i.e., MS-A), TD, and EMD Phases.

The CCRL process is the vehicle for interfacing component competition into the systems engineering (SE) acquisition process, whereby CCRL activities are identified and enhance the development of component competition. The CCRL process goals will ensure that a way of measuring the “openness” of a system is how readily a system component can be replaced with one developed by a different vendor, with no loss in overall system effectiveness. The CCRL process adheres to the principles of MOSA-NOA. The program achievement of these five principles will allow qualified third parties to add, modify, replace, remove, or provide support for a component, based on open standards and published interfaces. Key CCRL criteria can be specified for each of the system engineering phases leading up to a major program milestone, and it is important to establish these criteria across the full life cycle in order to build component competition into the system.

MS-A Phase

During the MS-A phase, most of the CCRL related activities, criteria, and results can be mapped to content of the MS-A Program Open System Management Plan (OSMP) (see **Figure 10**). Associated MS-A engineering analyses engineering analysis, which includes the following:

- Establish OSA Training Workforce
- Establish OSA Policy & Guidance
- Establish a Strategy for Unlocking Vendors at a Component Level
- Establish a Data Rights Strategy
- Perform Initial Key Open Sub Systems (KOSS) assessment, the process which defines subsystems/components that have the potential to yield the greatest benefit to life-cycle affordability by applying MOSA principles
- Achieve a CCRL of 2 by Milestone A
- Identify product platform ecosystem and establish node connection to the ecosystem network

The MS-A Phase provides a business and technical approach for Modular OSA to enable competition.

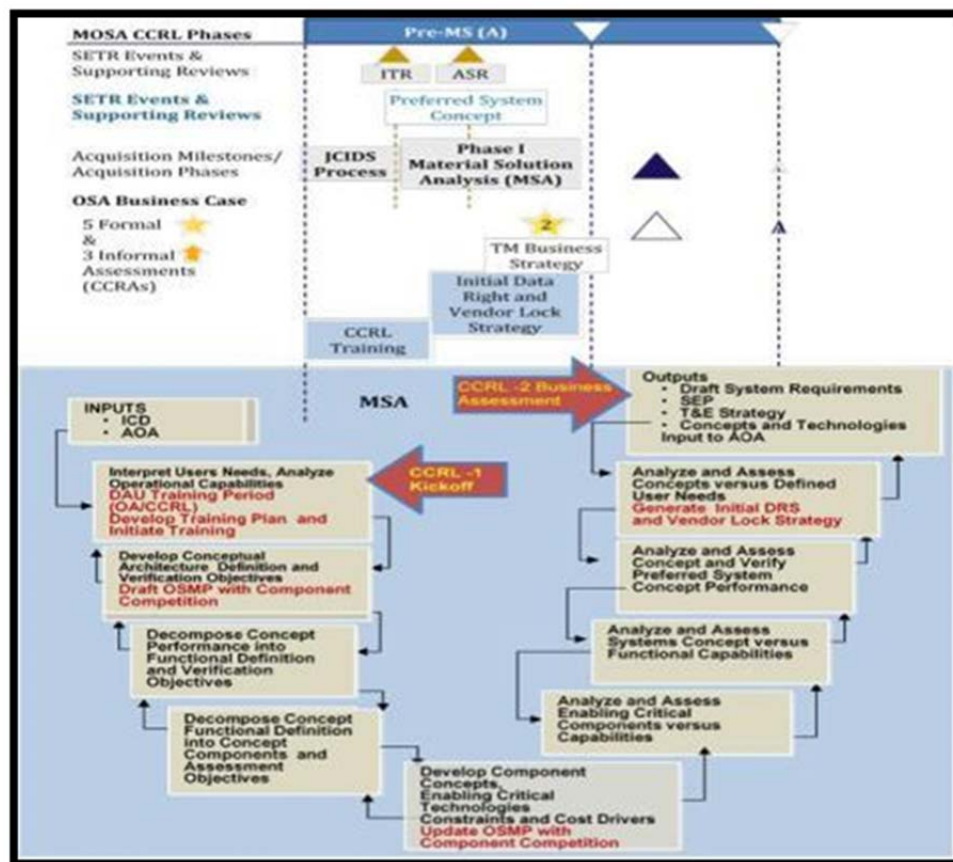


Figure 10. MS-A CCRL Roadmap with Supporting Processes

Technology Development (TD) Phase

During the TD phase, most of the CCRL related activities, criteria, and results can be mapped to content of the Milestone B OSMP (see **Figure 11**). Associated TD engineering analyses and OSMP content include the following:

- Systems requirements and technology development
- System architecture and technology demonstration
- Establishment of a Long-Range Volatility Capabilities Roadmap
- Performance of a KOSS Assessment to identify components for competition
- Identification of Key Interfaces to enable Competition
- Alignment of a Unified Data Model Strategy, Tools, and Process
- OSA with Component Competition Roadmap
- Achieve a CCRL of 6 by Milestone B

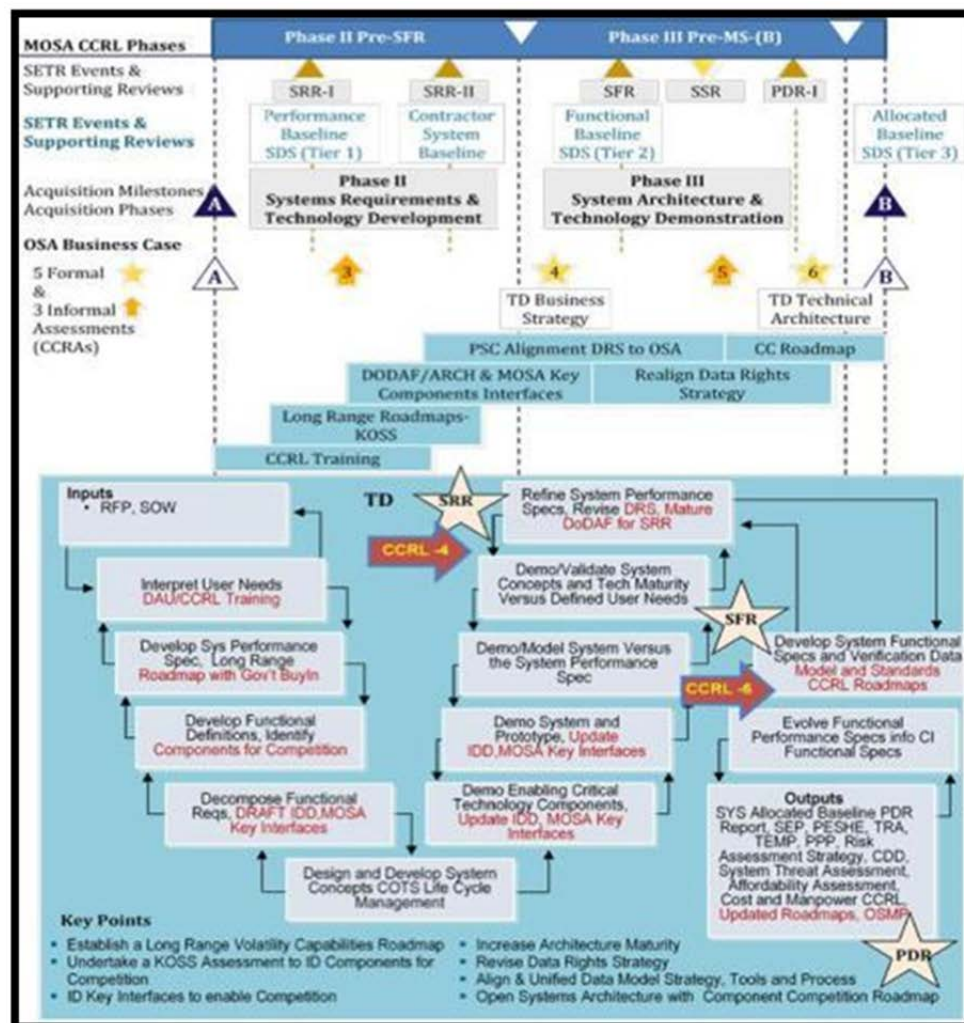


Figure 11. TD CCRL Roadmap with Supporting Processes

Engineering and Manufacturing Development (EMD) Phase

During the Engineering and Manufacturing Development (EMD) phase, most of the CCRL related activities, criteria, and results can be mapped to the content of the Milestone C Program OSMP (see **Figure 12**). Associated EMD engineering analyses content include the following:

- Provides data model/processes
- Addresses testing for OSA components
- Aligns OSA with Component Competition Roadmap
- Achieves a CCRL of 9 by Milestone C

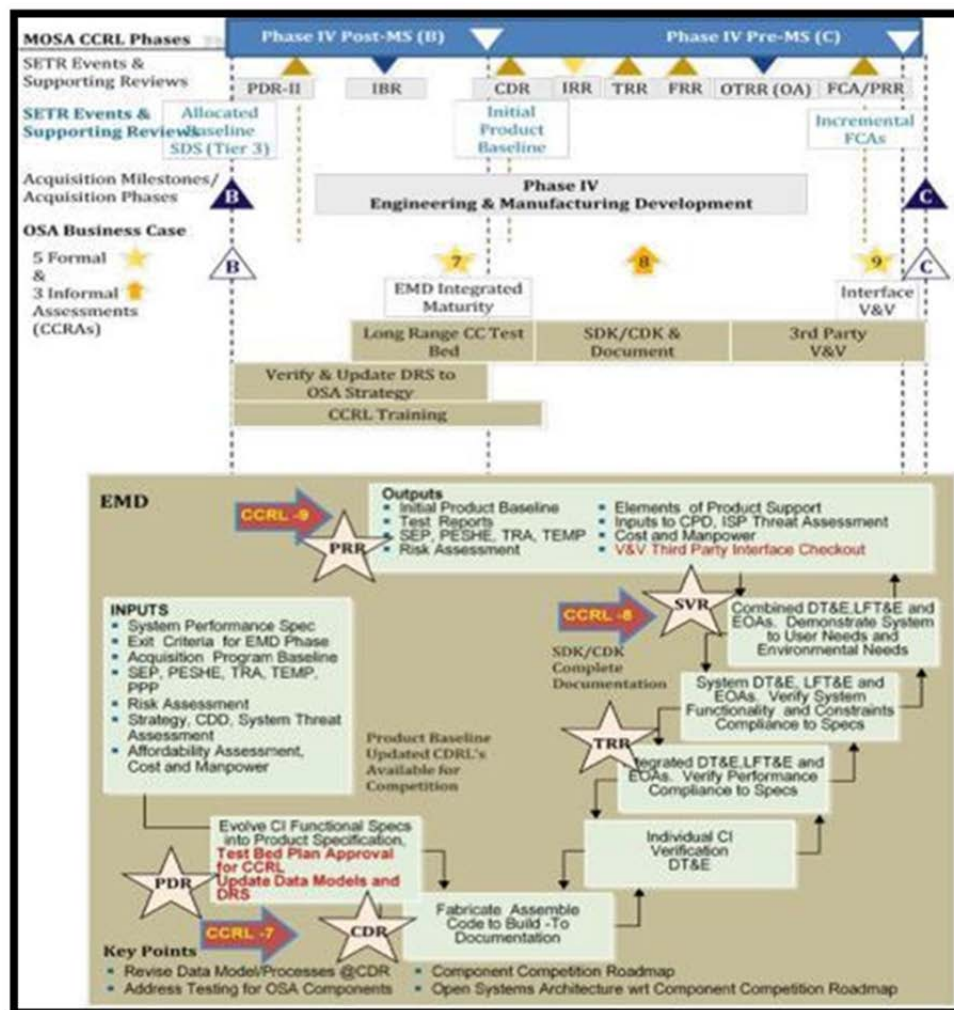


Figure 12. EMD CCRL Roadmap with Supporting Processes

CCRL Certification and Piloting

CCRL processes have to be designed to produce verifiable artifacts that can be used to certify compliance as shown in **Table 2**.

Table 2. Representative CCRL Definition and Alignment with TRL

TRL/CRL Rating	DoD Product TRL Definitions	CCRL Definitions
1	Basic principles observed and reported	(New platform) Blank (Legacy P31) Technical open with business closed (locked-in) from Government's POV
2	Technology concept and/or application formulated	Outline an open competitive business strategy and product platform ecosystem (Min. vendor lock and initial Data Rights Strategy)
3	Analytical and experimental critical function and/or characteristic proof of concept	Establish long-range volatility capabilities (post IOC) roadmap
4	Component and/or breadboard validation in laboratory environment	Identify components (what and what not) to compete AND Assess system/architecture in support of competitive ecosystem
5	Component and/or breadboard validation in relevant environment	Realign revised DRS with components for competition
6	System/subsystem model or prototype demonstration in a relevant environment	System/components Data Model Strategy, tools and process established AND For each component show a logical flow via a Component-to-System Competition Roadmap
7	System prototype demonstration in an operational environment	System prototype mature Data Models AND Implement a System V&V competitive environment
8	Actual system completed and qualified through test and demonstration	Actual system completed and releasable SDK/CDK for all components AND measure diversity of supplier ecosystem for competitiveness
9	Actual system proven through successful mission operations	Actual systems tested for competition through independent V&V of SDK/CDK

MS-A TD EMD

The next step is to pilot the CCRL concept with the above CCRL matrix. A program in a TD phase is a good candidate for piloting. By collaborating with the program office, first, assess the CCRL level as it is. It is expected that the CCRL level would be accessed as low as Level 1 or 2. Then, following the progression of the CCRL matrix, create a plan that lays down a course of action to raise the CCRL level to 6 or higher at the end of the TD phase. The first step is outlining an open competitive business strategy for the program, and laying out an approach to create a product platform ecosystem. At minimum, this initial strategy should address how to avoid a vendor lock in any phases of the program, and establish a proper data right strategy, which directly supports the creation of an OAM. The time frame of this strategy ought to address both the IOC and post-IOC period.

Next, identify major components in the context of the platform chosen, and classify them into two groups: competing and non-competing components in the OAM ecosystem. Not all components need to be competed. They must be examined from a low-volume, long-term, product cycle-life affordability driven perspective. Most commercial products don't support an infrastructure that has a product life of 20–40 years. The goal is the best valued OAM ecosystem for the DoD, while preventing programs from a single vendor lock. The resulting OAM ecosystem is expected to be a scale-free network with desirable agility and robustness.

As the OAM ecosystem evolves, DRS needs to be realigned and revised to reflect the latest OAM ecosystem landscape. This ensures a continual evolutionary progression of the layered hourglass OAM architecture by encouraging suppliers remaining in the market to continue competing, while luring new entries in the OAM ecosystem. Also critical is creating or fostering an open tool vendor market, which further optimizes the OAM ecosystem by reducing the cost of producing components. Perhaps the most critical is to identify candidate OAs, evaluate in a real

program execution context, and narrow down to a single open architecture that enables the formation of a well-functioning layered hourglass OAM ecosystem. Unmanned aerial system (UAS) UCS Architecture, The Open Group FACE, OMS, and ARCI are some examples of OAs designed to support the OAM ecosystem. Components, tools, DRS, and a strategic platform, along with carefully chosen standards and an open architecture, complete the construction of the OAM ecosystem.

Fortunately, the CCRL process and its compliance levels are not completely tangential to the DoDI 5000.02 acquisition process. One great integration point is the Acquisition Strategy document, which is one of the documents required to be submitted as an entry condition of Milestone B evaluation by the Milestone Decision Authority (MDA).¹⁹ For example, the CCRL compliance level is readily included in the Open System Approach of Acquisition Approach section of the Acquisition Strategy document. Business Strategy and Resource Management sections of the same document are also additional anchor points to integrate the CCRL concept and compliance level.

Out of the first piloting effort of the CCRL concept and CCRL compliance matrix, the effectiveness of the CCRL will be tested and evaluated in the context of a real acquisition program. All lessons learned will be documented and used to mature the CCRL concept, matrix, and process.

Additionally, we also propose a research effort to perform a qualitative formulation of the scale-free network behavior and its effect in the OAM ecosystem. The research outcome will greatly improve our understanding of the scale-free network behavior in an OAM ecosystem, and provides a theoretical underpinning to manage/manipulate the OAM ecosystem.

ACQUISITION AT THE EDGE OF CHAOS

SE practices have become stagnant. They were designed to perform tasks accurately, predictably, and repeatedly, but not to continually modify their behavior in reaction to a dynamic environment and to solve a range of problems. In the language of complexity theory, current SE and the supporting acquisition model have developed to support a steady state system of the Cold War world. A complementary SE and acquisition model is needed for the world faced with a dynamic and asymmetric warfare that is based on complex adaptive systems.

The CCRL defines and measures competition readiness at the component level to promote agility into the complex dynamics of the acquisition processes. CCRL is a set of specific OSA and ecosystem health related tasks. Tasks are applied to the capability-driven acquisition model.²⁰

According to a new University of British Columbia study published in the *Proceedings of the Royal Academy*, social connectedness is crucial for the development of more sophisticated technologies. A Stanford University study has also suggested that social networks may be contributing to increased intelligence among the young.²¹ This is an emergent benefit of a scale-free network behavior in social networks.

As shown by OSS, the DoD acquisition model needs the power of the network by creating ecosystems around product platforms and eliminating closed-source development teams in favor of communities consisting of developers, co-developers, and active users. Co-developers and active users are generally not part of a closed development team but are required for product innovation process. It will truly instantiate a workable framework and process for the BBP

(<http://bbp.dau.mil/>) of the Under Secretary of Defense for Acquisition, Technology, and Logistics, Honorable Frank Kendall.

KEY CONTRIBUTORS

Niraj Srivastava	Dr. Niraj Srivastava is a Senior Manager at Raytheon SAS responsible for emerging solution and technology for Cyber Operations and Multi-INT programs. Niraj has extensive experience with cyber systems and HPC computing with a long history of working in the Intelligence Community, DOD and the Department Of Energy. He has contributed to large scale Simulation and Modeling efforts in DOE and Oil & Gas besides having made fundamental contributions in the area of nonlinear dynamics and quantum chaos. He holds a Ph.D in Physics from University of Rhode Island.	Dr. Niraj Srivastava 1001 Boston Post Road East Marlborough, MA, 01752, 202-904-2181 niraj.srivastava@raytheon.com
Mike Rice	Mr. Michael "Mike" L. Rice is President, R2E Inc., a Veteran Owned Small Business. Mike works under contract with the Naval Space and Warfare Systems Command, San Diego, California, through subcontract with AUSGAR, Technologies, Inc. Mike directly supports the SPAWAR 5.0, Chief Engineers Staff, who is the CHENG's C4I Systems Engineer (CSE) Action Officer to the DASN RDT&E lead OA Enterprise Team. Mike possesses an M.S. Computer Science, Naval Post Graduate School and a Graduate of DAUs Program Management Course; and a former DAWIA Certified SPRD&E Acquisition Professional.	Mr. Michael L. Rice R2E, Inc. 2004 Victoria Dr. Stafford, VA 22554 540-720-0454 mrice.r2einc@verizon.net
David Kwak	Dr. David Kwak is Engineering Fellow Raytheon SAS. He has been leading research and development efforts in areas of Architectures, Modeling and Simulations, Complex Adaptive Systems (CAS), Net-centric Service Oriented Architectures (SOA), Robotics, and Artificial Intelligence for more than 30 years for United States Air Force, Army, Navy, Marine Corp and Joint Forces customers. He has been serving as Chief Architect, Technical Director, and Chief Scientist during his tenure at Raytheon, Hanscom Air Force Base, and Lockheed Martin. Before making transition to industry, Dr. Kwak was computer science professor at Naval Postgraduate School.	Dr. David Kwak 1001 Boston Post Road East Marlborough, MA, 01752 978-930-3627 david.kwak@raytheon.com

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ACRONYMS

Acronym	Definition
API	Application Programming Interface
ARCI	Acoustic Rapid COTS Insertion
ATM	Asynchronous Transfer Mode
BBP	Better Buying Power
CAS	Complex Adaptive Systems
CCR	Component Competition Readiness
CCRA	CCR Assessment
CCRL	Component Competition Readiness Level
CDK	Component Development Kit
CDR	Critical Design Review
COD	Capability on Demand
COTS	Commercial Off The Shelf
DoD	Department of Defense
DRS	Data Right Strategy
EMD	Engineering Manufacturing Demonstration
F2F	Face-to-Face
FACE™	Future Airborne Capability Environment
GPR	Government Purpose Right
HOL	Hands on Lab
I/O	Input/Output

Acronym	Definition
IOC	Initial Operations Capability
IP	Intellectual Property
IPV4	Internet Protocol Version 4
IPX	Internetwork Packet Exchange
JCIDS	Joint Capability Integrated Development System
KOSS	Key Open Sub System
LSI	Lead Systems Integrator
M&S	Modeling and Simulation
MBE	Model Based Engineering
MDA	Milestone Decision Authority
MIL-STD	Military Standard
MOSA	Modular Open Systems Architecture
MS-A	Milestone A
MS-B	Milestone B
MS-C	Milestone C
NDIA	National Defense Industrial Association
NOA	Navy Open Architecture
O&S	Operational and Support
OA	Open Architecture
OAM	Open Acquisition Marketplace
OAAT	Open Architecture Assessment Tool
OMS	Open Mission Systems
OSA	Open Systems Architecture
OSMP	Open System Management Plan
OSS	Open Source Software
PART	Program Assessment and Rating Tool
PB	Personality Band
PBE	Platform Based Engineering
PDR	Preliminary Design Review
PLA	Product Line Architecture
POV	Point of View
RDT&E	Research Development Test and Evaluation
ROI	Return on Investment
RT	Real Time
SDK/CDK	Software Development Kit / Component Development Kit
SE	Systems Engineering
SOA	Service Oriented Architecture
TD	Technology Development
TM	Technology Maturation
TRL	Technology Readiness Level
UAS	Unmanned Aerial System
UCS	UAS Control Segment
USD AT&L	Under Secretary of Defense for Acquisition, Technology and Logistics
V&V	Verification and Validation
WBS	Work Breakdown Structure

Space and Airborne Systems
Raytheon Company
2000 El Segundo Blvd.
P.O. Box 902
El Segundo, California
90245-0902

www.raytheon.com

Dr. Niraj Srivastava
202.904.2181
niraj.srivastava@raytheon.com

Mr. Michael L. Rice
540.720.0454
mrice.r2einc@verizon.net

Dr. David Kwak
978.930.3627
david.kwak@raytheon.com

Raytheon

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