A Roadmap-Based Framework for Acquiring More Agile and Responsive C4I Systems

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***Abstract*–To deliver Net-Centric capabilities more quickly and more responsive to the warfighter's needs, the C4I system acquisition processes themselves must become more agile and adaptable. This whitepaper outlines some of the major challenges in acquiring C4I systems today, and presents an innovative approach to address these challenges using Net-Centric principles. The approach employs a roadmap-based framework that systematically identifies and manages the mission capabilities, services, and acquisition activities, with end-to-end traceability across them.**

This framework serves as an invaluable tool for managing an acquisition program's technical baseline, and allows the organization to truly reap the benefits of SOA and Net-Centricity. This roadmap approach is being practiced at the program, enterprise, and community levels across the Defense, Intelligence, and Civil sectors of the Government. The paper concludes with risk mitigation mechanisms and practical guidelines on how to successfully execute the roadmap approach.

I. Trends And Challenges In Acquiring C4I Systems

With the signing of the McCain-Levin bill [1] on reforming weapon system acquisition as well as increased public attention on federal budgets, much as been publicized about the prolonged life cycles and significant cost overruns of defense acquisition programs [2]. Although the debate is still raging on how to best improve the current acquisition policies and processes, it has been widely acknowledged that the monolithic system thinking is one of the fundamental causes of the problem, namely, building modern warfighting capabilities from ground up – as "silos" of stove-piped systems – just like the way we build tanks or rockets. As one Air Force officer deftly puts it, we are building information age systems with industrial age acquisition policies. Let's take a deeper look at some of the key challenges the acquisition programs are facing today:

Victims of Moore's Law. C4I systems are increasingly becoming software-intensive IT systems, often with Software Line of Code (SLOC) reaching millions or more. IT systems, as the famed Moore's Law dictates, enjoy an exponentially growing performance-price ratio, roughly doubling every 18 months. Because C4I systems still follow a more or less linear growth model for their acquisition and sustainment, many of them now fall victim of the Moore's Law rather than reaping the benefits of it. For one thing, commercially-available hardware / software platforms quickly render the custom-built, special-purpose systems obsolete, however sophisticated they were when first designed. In today's increasingly complex global environment with non-traditional actors and asymmetric threats, this should be viewed as not merely an acquisition conundrum but a national security issue – just imagine how an adversary can put together equivalent warfighting capabilities quickly and cheaply with Commercial Off the Shelf (COTS) products.

Lack of (good) requirements. Today's system acquisition life cycles assume a relatively rigid set of requirements captured up front. However, the dynamic and changing mission needs in today's asymmetric warfare are making upfront requirement capture difficult if not impossible. Even when the user needs do get defined, they often get "stale" during the course of system development and fielding. The emergence of web 2.0 technologies are further exacerbating this: Armed with the ability to quickly "mash up" information widgets from disparate sources, users are now creating innovative services themselves and sharing them with others in unanticipated ways – it has been reported that junior officers were organizing their squadrons using Facebook [3]. In such a networked and collaborative operational environment, even the very notion of "application" or "system" is getting challenged.

Woes with ad-hoc solutions. Many C4I acquisition communities are facing this dilemma:

- Acquisition of the "programs of record" (PoR) usually follows a lengthy process. The waterfall-like, single-vendor, and risk-averse nature of the process is

not conducive to innovative solutions, nor adaptable to change in user needs.

- In the mean time, warfighters scramble to meet current mission needs with whatever they can get, and one-off, home-grown solutions often sneak into the operational environment.
- These ad-hoc systems soon begin to compete for Operations and Maintenance (O&M) resources, and also makes the existing operating environment difficult to sustain – many quickly becoming legacy systems themselves.
- The enterprise's ability to delivery the PoR systems gets further strained, resulting in a vicious cycle.

The overall challenges of C4I system development and acquisition may be summarized in a simple diagram in Figure 1: Under the traditional acquisition, architecture, and engineering practices for C4I systems, their complexity and cost grows exponentially as they attempt to grow (partly due to the n^2 point-to-point interconnections among different system components), at a rate that is much faster than that of the intended performance and functionality. It is when the cost starts to surpass benefits, as indicated in the shaded region in the diagram, that programs and initiatives start to fail.

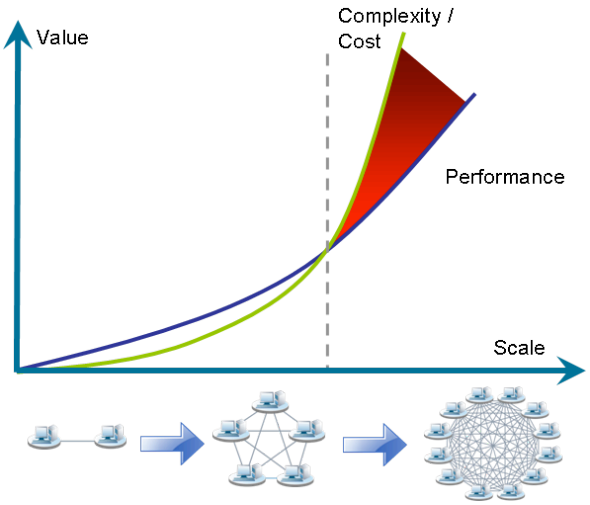


Figure 1. Cost and complexity for traditional C4I systems quickly surpass their performance as they grow

Unless this status quo is changed and the acquisition process becomes more Net-Centric, agile and responsive, our ability to meeting warfighters' C4I needs will continue to be severely impaired.

II. What Needs To Be Changed ?

In light of these challenges, the acquisition community needs to rethink WHAT we are building for our warfighters and HOW we deliver them. Fortunately, there are encouraging signs for change: from the Department of Defense (DoD) [4] and the Intelligence Community (IC) [5] enterprise level policies and directives, we can see maturation in strategic Net-Centric thinking from top-down; from various C4I acquisition programs we can see concrete engineering and cultural changes towards Service Oriented Architectures (SOA) from bottom-up. Here are some the valuable insights we have gleaned:

Services, Not Applications. As aforementioned, answering users needs with large and complex custom applications is becoming very problematic even in the requirement phase. Rather, the goal should be providing warfighters (1) a generic presentation layer (such as a User Defined Operational Picture environment), (2) a set of mission and data services, (3) a robust and secure SOA infrastructure that hosts and connects the two – and then let users configure all three for their own optimal use.

Assemble, Not Develop. When the overall "system" of interest is decomposed into a set of services, it becomes apparent that not all need to be built from scratch. In fact, not all need to be owned by the acquisition program itself. With service orientation, the methodology for the overall system design is changing, especially for large Systems of Systems – the focus becomes not so much on the processing logic, the control flow, or other lower-level engineering such as storage or timing, but rather on how to effectively structure the levels of abstraction, how to define the interfaces among disparate software components, and how the composition thereof achieve the overall capability objectives.

Evolutionary Acquisition and Sustainment. There is no doubt about the need to get new capabilities out to the users quickly. Faster deliveries will provide valuable operational feedback which can become "vector checks" for the overall program. The early introduction of new capabilities, however, should be orchestrated and controlled so that training, Tactics, Techniques and Procedures (TTP), and business processes can be put in place to support them. Service orientation is the key enabler for more evolutionary delivery of capabilities while maintaining a coherent overall architecture. With SOA, system evolution can even continue in sustainment phase, just like we can replace or upgrade parts in a personal automobile during its long lifespan.

When such SOA tenets and principles are truly put to practice, they start to fundamentally change the economics of system acquisition, as shown in Figure 2. Specifically, when an overall mission capability may be realized by a set of loosely coupled services with standards based, platform-independent interfaces (analogous to Lego® pieces in many respects), the overall system complexity is in theory reduced to a linear relationship to the system scale, while the performance of the system is boosted by the "networking effect" of the connected services (as described by the Metcalfe's Law). Such a "System of Services" may require a larger upfront investment, but will eventually enjoy the benefits of performance surpassing cost as it scales.

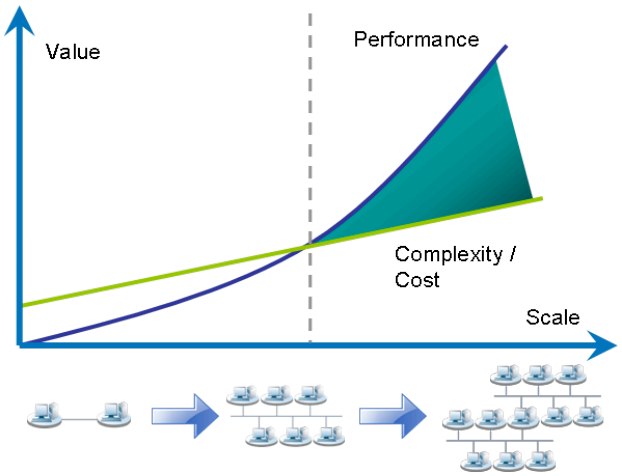


Figure 2. SOA changing the economics of C4I system acquisition

III. The Roadmap Framework

Acquiring such SOA based systems, however, brings new challenges. Even though the architectural complexity of the system is significantly reduced, the management complexity of the acquisition efforts becomes much amplified. Program Managers are often faced with questions such as:

- What web services / applications do I need to build to support a mission capability, and when?
- What are my top priority services and why?
- How do these services work together to satisfy capability requirements? Do I have redundancies or gaps?
- How much will these services cost? Alternatively, given a specific level of funding, what services can I build to maximize the "bang for the buck"?

Existing acquisition disciplines such as Enterprise Architecture, Systems Engineering, and Program Management are still largely following non-SOA practices and not prepared to answer these questions in a timely and accurate fashion.

In this paper we propose a multi-disciplinary approach based on experience supporting various DoD acquisition programs. The centerpiece of the approach is a program-wide SOA roadmap framework, illustrated in the diagram below.

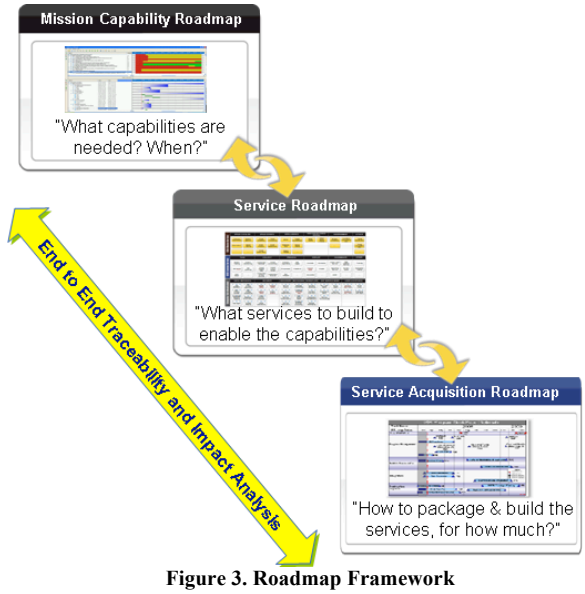


Figure 3. Roadmap Framework

The framework consists of three inter-connected and inter-dependent roadmaps:

The **Mission Capability Roadmap (MCR)** answers the question "what capabilities will be available to operational users, and when". It is driven by the enterprise strategic vision, high level program requirements such as the Capability Description Document (CDD), and / or mission priorities from the user community. The capabilities are systematically decomposed along functional, mission, and organizational dimensions. The capability timelines are usually color-coded (e.g. red for lack of capability, green for meeting CDD thresholds, etc.) to provide a high level summary of capability delivery over time. An example of the MCR is shown in Figure 4 (a).

The **Service Roadmap (SVR)** answers the question "what net-centric services will be needed to satisfy the mission capabilities, and when". The service roadmap is constructed around a Service Portfolio which organizes services around a pre-defined service taxonomy. For example, the taxonomy may include top-level service layers, which then include service families.

Typical service layers may include:

- Mission Services, which are operationally relevant, mission driven, and directly tied to user needs;
- Shared / Common Services, which may support multiple missions within a Community of Interest (COI). Such services may often reduce overlap and redundancy across different acquisition programs;
- Enterprise Infrastructure Services, which are the enterprise-wide SOA "plumbing" and not specific to a particular program or community. Net-Centric Enterprise Services (NCES), for example, may constitute such a layer.

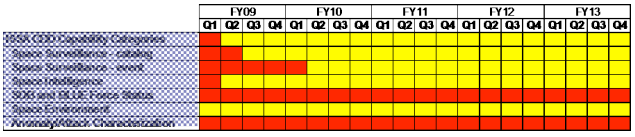
Alternatively, the services may be organized into functional layers such as presentation services, aggregation services, and data services.

Service identification and prioritization is based on the Mission Capability Roadmap and is therefore deeply rooted in the operational context. The service roadmap also provides a time-sequence view of when the services will be implemented in accordance with mission priorities, as well as the interdependencies among the services. An example of a service roadmap is shown in Figure 4 (b).

Thirdly, the **Service Acquisition Roadmap (AQR)** reflects the detailed execution of acquisition activities around the services, and answers questions such as "what developers will be developing what services? what integration events and milestones are needed to integrate them together? How are these activities sequenced?" The acquisition roadmap is particularly useful when rapid, incremental capability deliveries are necessary. For example, the services from the portfolio may be sequenced into Service Delivery Packages (SDP), each of which is tested, certified, and fielded as a whole to meet a subset of capability needs. This is depicted in Figure 4 (c).

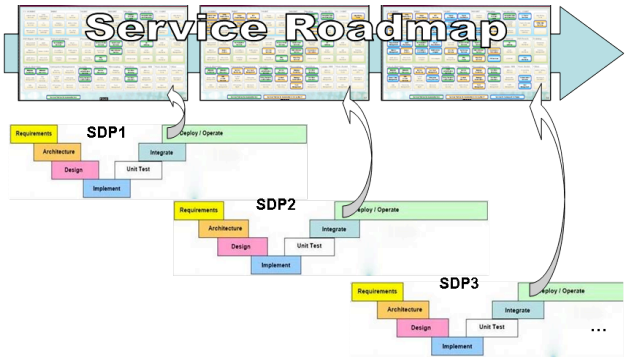
The concept of evolutionary acquisition has been formally recognized in the latest publication of the DoD 5000.02 policy, and should therefore be applicable in large-scale (MAIS) acquisition programs as well. Depending on the scale and milestone requirements (either DoD 5000 or IT Lean Processes) of the program, the "battle rhythm" of incremental deliveries can be from a few months to 1 year or more.

Events and inchstones identified in the acquisition roadmap can be used as input to the program's Integrated Master Schedule (IMS) and managed within the system engineering processes.



(a) Mission Capability Roadmap

(b) Service Portfolio & Roadmap



(c) Service Acquisition Roadmap

Figure 4. Roadmap Example

To see how all three roadmap components work together, consider this following example:

- On the Mission Capability Roadmap, the program manager sees that a Key Performance Parameter (KPP) is met (i.e. turns green) at the end of First Quarter of Government Fiscal Year 2010 (GFY10);
- To understand why, the program manager "zooms in" to the service portfolio and see that this particular KPP relies on four mission services, 3 of which already exists and the 4th is a new service to be developed;
- The program manager further learns from the Acquisition Roadmap that, the new service is part of the Increment 2 delivery, which is scheduled to past Operational Test (OT) in June 2010. This explains the capability turning green at that time.

The roadmap framework is an evolutionary construct and does not live in vacuum. The three roadmap components are developed using a rigorous, multi-faceted process that involves SOA, Enterprise Architecture, Systems Engineering, and Program Management disciplines along with domain expert input.

IV. Roadmap As A Management Tool

With the three component roadmaps in place and managed in a single repository, an end-to-end traceability is established:

- Mission capability needs are decomposed into Net-Centric services;
- Services are allocated to developers to implement;
- Service implementations are integrated as Delivery Packages;
- Service Delivery packages, when fielded, satisfies mission capabilities

As such, the roadmap is not merely another report or Enterprise Architecture product, but rather a living "baseline" for the acquisition effort that ties capability, cost, schedule and risks together – four key elements that are all-too-often disjointed and misaligned in today's acquisition endeavors. In addition to providing a path forward for Net-Centric solutions,

the roadmap framework can help decision makers assess impacts and conduct "what-if" analyses. For example,

- With the SOA services identified so far, do we have any gaps in capabilities?
- With a $\$\chi$ million dollar funding short fall, what services will be impacted, and consequently what capability requirements will we not meet?
- An urgent mission need arises from the user community; to what extent can it be met with existing services in the portfolio, and what new services need to be developed, and how will that impact my project schedule and funding profile?

Such questions are no longer answered with subjective estimates or arbitrary guesses, but by logical deductions from the roadmap. As we discovered from recent engagements, when the roadmap is established for a program, it quickly becomes indispensable for the PM staff.

V. Benefits Of The Framework

In addition to being an invaluable tool for managing the acquisition program's technical baseline, the roadmap framework also allows the acquisition effort become intrinsically Net-Centric, thereby truly benefit from it. Specifically, the approach delivers the following value propositions:

- Enables parallelization of service acquisition (via well-defined service specifications, see later), thereby shortens delivery timeline. For example, procurement of presentation, data, and infrastructure services may happen concurrently
- Faster and more adaptable capability to warfighters with incremental service deliveries
- Reduces duplication of functionality and infrastructure
- Produces vendor agnostic interface designs, and acquisition at the service level
- More latitude in employing innovative technologies and best-of-breed solutions
- A flexible framework that can be applied at enterprise, community, or program levels

VI. Key Success Factors

The roadmap framework is a means, not an end. To fully reap the benefits, the enterprise or acquisition program must pay extra attention to a few key success factors, as described below. They serve as essential risk mitigation mechanisms to ensure the effective construction and application of the roadmap throughout the acquisition process.

Drive service development and integration with well-defined service specifications

Service specifications (see Reference [6] as a well known guide) are the engineering rigor behind the service roadmap, and are the prerequisite for decoupling and parallelizing service development / integration activities. The service specifications can complement or in some cases replace traditional Techncal Requirement Documents (TRD) as the definitive requirement set issued to the service developers. Like the service portfolio itself, the service specifications should be defined, managed, and owned by the enterprise. Some, however, may be concerned that service specifications are "B-Specs" that should be left at the discretion of the developer. Not so. Unlike traditional Interface Control Documents (ICDs) that are solution specific, the service specifications are codified using platform-, vendor-, and technology-independent standards such as XML Schemas and WSDLs, which ensure enterprise-level interoperability while leaving ample room for engineering innovation by the contractors.

Service specifications also are the conduit for applying controlled information exchange vocabularies defined by the enterprise and the COIs. For example, the specification can dictate the web service returns XML elements that are compliant with the UCore [7] schema.

Engage the community

Social engineering for the roadmap is crucial. All stakeholders from operational, acquisition, and engineering communities should be involved from the very beginning, to promote the concept, obtain buy-in, and more importantly, to advocate the portfolio-driven vs. system-driven mindset, and get everybody to think "enterprise".

"Check and Balance" in the acquisition strategy

Without clear delineation of roles and responsibilities in the acquisition strategy, the resulting system easily becomes another tightly coupled stovepipe. Ideally, the acquisition strategy should distinguish among three different engineering roles:

- an **Enterprise Capability Architect** as the managing authority for the roadmap, service portfolio and service specifications
- a **Service Integrator** which is precluded from service development but focus only on integrating and operationalizing service implementations
- one or more **Service Developers** that focus on implementing services in accordance with service specifications

By providing separate contract vehicles and incentives, the three roles can work in tandem and provide the proper "check and balance" to ensure overall agility, interoperability, and operational relevance of the resulting system capability.

Establish strong System Engineering (SE) processes

The roadmap, with its mission capability, service, and acquisition components, constitutes the technical baseline for the acquisition effort, but there must be a set of rigorous SE processes around it, such as Requirements Management, Configuration Management, and Risk Management. Additional SE disciplines, such as Modeling and Simulation, and Technical Performance Measure (TPM) management, are

also necessary and are only made more effective with the roadmap.

Recalibrate Test and Evaluation (T&E) and Information Assurance (IA) processes

As witnessed in a couple of recent C4I programs in the Air Force and the Army, well-defined service portfolios and specifications increased the testability of service implementations, expedited test planning, and reduced Development Test (DT) and Operational Test (OT) time by identifying deficiencies early. To capitalize on the roadmap approach, the T&E community must be involved from the beginning so that they can to leverage the service portfolio and other engineering products for test planning, without having to wait for delivery of the service implementations. Once again, education and communication is key! The same holds true for the IA community. In many cases there need not be any revolutionary policy changes, "cutting corners" or bending rules; rather the IA staff just need to have insight into the service-based Net-Centric capabilities and plan their work accordingly. For example, a good understanding of security services (as part of the SOA infrastructure layer in the portfolio) and how mission services integrates with them will eliminate a lot of confusion and speed up the Certification and Accreditation (C&A) process.

Even with a well-managed roadmap, large-scale mission system acquisition remains a complex effort that needs to be delicately orchestrated across both the Government and the contractor teams and along the people, process, and technology dimensions.

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