Organizing for a Complex World: The Way Ahead

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Abstract

Complex defense and network-centric systems have proven to be difficult to develop on time and on budget, a consequence of the complexity inherent in both the systems and the acquisition environment. Complexity in turn results from non-linear, unpredictable interaction of elements combined in new ways, in order to try to create unique capabilities. Complex development programs pose governance and management challenges for a range of systems-integration models, and it is difficult to know in advance the program-management model most suitable for a given program. This paper proposes ways to measure or assess success in managing complex programs. It also addresses ways that the challenge of picking the proper development model can be partially bypassed, by seeking to cultivate *flexibility* and *resiliency* (F&R) within the organization. Through the ability to understand and adapt to changes in the internal and external environments, a program-management organization can thrive in a development environment in which unanticipated events will certainly occur.

Introduction

Complex defense and network-centric systems, such as the Army's Future Combat System (FCS), the Coast Guard's Integrated Deepwater System (IDS) and the FAA's Next Generation Air Traffic System, have been shown to be far more ambitious than any previously attempted by the U.S. government. Successfully managing these complex programs is vital, because they were designed to provide the core of many critical future national security capabilities. This is true even though the Secretary of Defense has proposed restructuring the FCS program.

Such systems are difficult to develop and oversee. They incorporate technology that was not yet created when the systems were still on the drawing board. These programs are actualized by a team of government managers and industry practitioners, aided by a vast assemblage of engineering and scientific talent, overseen by political forces, monitored by auditors at every step, regulated by rules measured in linear feet, and ultimately evaluated in life-and-death situations. This is tough, difficult work.

For the government, managerial techniques struggle to keep up as complexity blossoms, often resulting in blown budgets and missed schedules. Our research concludes that such overruns are rarely the fault of the organizations or the personnel involved. Rather, they result from the overwhelming difficulty of creating systems comprised of thousands of elements, addressing dozens or hundreds of requirements, produced by multiple manufacturers under the direction of one of a handful of prime contractors. Producing a state-of-the-art weapons system has proved to be demonstrably difficult. The fact that problems appear regardless of how programs are managed does give us insight, however, and points toward a potential solution. We conclude that successful management of complex programs requires the government to make sure that whatever model it uses, that model can easily recognize and adapt to the challenges complexity will pose.

In a recent CSIS book, "Organizing for a Complex World: Developing Tomorrow's Defense and Net-Centric Systems," several models were put forward for rethinking the policy framework in which complex programs are developed. Upon reviewing these models, one key question emerges: how can program managers and policymakers choose the model most appropriate for each program? In other words, how can they measure, compare and assess the relative value of alternatives? And once a governance model is selected, how do policymakers and managers implement it to cope with the inevitable unintended consequences and unexpected developments that accompany complexity?

We posit that policy makers, in their efforts to select the right model to govern and manage a given defense acquisition program, should focus less on making exactly the right choice and more on ensuring that whatever option they do select can successfully identify, survive and respond to changes. In any large defense acquisition program, changes are inevitable, in user requirements, program scope, budget, outside political demands, and the operating environment. The impact of these changes is hard to anticipate, because of the complexity inherent in the program and its environment. And these impacts can best be handled by a program management model that embodies flexibility and resilience. We are not recommending a model. Rather, we are recommending an organizational way of life – attributes that a program-management organization must have, if it is to be able to manage and deliver complex projects successfully.

This paper describes the challenges that complexity brings to defense acquisition, highlights the need for a way to compare and assess governance models, and shows how the challenge of picking the right governance model can be augmented by ensuring that the model has flexibility and resilience. We define flexibility and resilience as the ability to recognize, absorb and react to changes in the development environment. We then suggest ways to achieve flexibility and resilience.

Complexity defined

It is easy to confuse "complex" with "complicated." Programs that seem complex to many observers are often better labeled complicated. *Complicated* systems are characterized by their large scale and by a multitude of moving parts or actors that are highly dynamic, that constantly interact with and affect one another, and that behave primarily in a linear fashion. Complicated programs are relatively common and can be managed to successful delivery by decomposing the program into subprojects and then using systems engineering techniques to identify and resolve (integrate) interdependencies across subproject boundaries.

Complex programs, on the other hand, are non-linear and are comprised of multiple, interrelated elements that interact unpredictably. Even an in-depth familiarity with each of these elements does not impart an understanding of the system as a whole. Complex programs are characterized by nonlinear feedback loops and recursiveness.

They are sensitive to small differences in initial conditions, and in their emergent phase this significantly inhibits the validity of any detailed long-term planning. They are often implemented in highly pluralist environments where multiple and divergent views exist at both the technical level and in management. Finally, complex systems cannot be deconstructed to their constituent elements; doing so would remove the added value that is provided when the systems integration function is undertaken as part of the entire system development. It is a fundamental characteristic of complex systems that the interplay of the various elements brings unique additional capability. Reducing the complexity of a proposed system could mean foregoing the capability it offers.

Historically, there has always been a tension between the increasing complexity of new technologies and the policy frameworks that govern and often lag behind their development. The recent track record indicates that the government's existing management and integration tools no longer suffice for large-scale, horizontally-integrated complex programs. Current approaches were developed years ago in an environment where the government customer was technically astute and worked closely with one vertically integrated contractor per program. Today, the government customer is less savvy in matters of technology and less well-staffed in terms of workforce. Moreover, the contracts for a typical program are executed by a network of firms, often spanning continents and sharing responsibility for managing cost, schedule and risk. Companies and even governments may simultaneously be partners and competitors, and it is a sensitive issue to even share information, much less to integrate it. Furthermore, dividing a program into more manageable smaller components, then integrating them into a single platform or system, is by definition not a viable option for complex programs.

Organizing for complexity: a constant struggle

The federal government's ability to bring complex programs to fruition depends first and foremost on effective governance. In the past, great engineering successes resulted not only from technical excellence but also from superior project management and governance structures. Unlike smaller projects, complex programs require that many external elements, such as the bureaucratic politics of coordinating a large number of interlinked organizations, be internalized. Integrating external and internal elements is part of what makes complex programs dynamic, non-linear and risk-intensive. It also presents significant policy and governance challenges.

With changing technological and commercial environments, program management models have evolved over the years, from the government-owned arsenal of the 19^{th} century to the recent Lead System Integrator (LSI) approach. Responsibility for requirements definition, program management and technical execution has increasingly shifted away from government and toward the private sector (see Table 1, Program Responsibility Format Types). This trend resulted from reasonable efforts to reap the benefits of competition in both innovation and economics.

Table 1: Program Responsibility Format Types

	Arsenal	Contract	Weapon System Manager	Outsourcing To Private Arsenal	Lead System Integrator
Program Requirements	Government	Government	Government	Government	Industry
Technical Direction	Government	Government	Government	Industry	Industry
Program Management	Government	Government	Industry	Industry	Industry
Technical Execution	Government	Industry	Industry	Industry	Industry
External Environment	▪ Infrequent wars ▪ Little commercial application of military tech	▪ Some commercial application of military tech ▪ Private sector private sector pays better, can be more responsive	▪ Weapons become more complicated / complex ▪ Coordination of sub-systems becomes important ▪ Large companies can better leverage political support	▪ Government begins to lose in-house tech capabilities ▪ Outsourcing becomes increasingly acceptable	▪ Loss of in-house government tech capabilities leads to inability to define what's possible

Source: Harvey Sapolsky (2009) "Models for Governing Large Systems Projects", in Guy Ben-Ari and Pierre Chao (eds.) *Organizing for a Complex World: Developing Tomorrow's Defense and Net-Centric Systems*, Washington, DC: CSIS, p. 26.

However, the shift of responsibility to the private sector has been accompanied by a decline in overall government expertise and capability. In fact, during the past two decades, the capability and capacity of the federal government for systems integration has been dramatically reduced. At the height of the Cold War, defense systems commands (such as the Naval Air Systems Command or the Air Force Systems Command) combined military, civilian, and outside personnel to build and manage large systems. Assistance with systems-of-systems integration was the purview of research centers and government labs. But at the end of the 1980s, the DoD began a long period of steady downsizing of the acquisitions workforce, and the expertise to manage complex acquisitions began to wither. The impact of the reduced staff numbers during the 1990s was not immediately apparent, as the pace of defense procurement in the post-Cold War world was slower and less urgent than before. The need for certification of new systems or examination of new standards was low. As a result, many of the design engineers and technicians employed by certifying organizations to develop and evaluate criteria for construction and design standards retired and were not replaced.[1]

Recent experience confirms the difficulty of managing complex system development programs to time and budget. Since 2000, the Department of Defense (DoD) has significantly increased the number of major defense acquisition programs (MDAPs) and its overall investment in them, but the track record of delivering on cost and schedule remains uneven. For example, in a 2009 analysis of select DoD weapon programs, the Government Accountability Office (GAO) found that for the fiscal year 2008 portfolio of MDAPs, total acquisition costs increased 25 percent and development costs increased by 42 percent, compared to initial estimates. Both increases are greater than the corresponding increases for programs in the fiscal year 2000 portfolio. GAO analysis also found that on average, FY 2008 programs delivered initial capabilities to the warfighter 22 months behind schedule, a 6-month increase compared to fiscal year 2000 programs. Continued cost growth results in less available funding for other DoD priorities and programs, while continued failure to deliver weapon systems on time delays providing critical capabilities to the warfighter.[2]

In directing programs that have been problematic, managers for the government, the prime contractors, and the commercial subcontractors shared one common feature: they underestimated the complexity of requirements, integration of subsystems, and the interaction of changes in one subsystem with new demands on others.[3] That is, while programs go awry for varied reasons, problematic programs have in common their inability to address the complexity challenge effectively.

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[1] Defense Science Board [DSB] Task Force on Integrating Commercial Systems into the DOD, Effectively and Efficiently, *Buying Commercial: Gaining the Cost/Schedule Benefits for Defense Systems* (Washington, DC: Department of Defense, February 2009), p. 30.

[2] Government Accountability Office (2009) *Defense Acquisitions: Assessments of Selected Weapon Programs*, Washington, DC: Government Accountability Office.

[3] David Berteau (2009) "Foreword," in Guy Ben-Ari and Pierre Chao (eds.) *Organizing for a Complex World: Developing Tomorrow's Defense and Net-Centric Systems*, Washington, DC: CSIS, p. ix.

Thinking about a solution: measuring success

As described above, complexity is first and foremost a governance and management problem. In today's globalized knowledge economy, the speed of change in technology and society has outpaced the ability of public policy and government organizations to learn, adapt and respond. Despite this, governance has found ways to individually and institutionally influence the ability to deliver military systems successfully.

But as complexity becomes a greater challenge, such solutions are less easy to find. Despite several efforts to identify innovative governance alternatives, there is no known or identified method to assess any of them *ex ante*. Therefore, it has been difficult for managers to compare potential solutions and to assess whether a given policy or governance framework will have the desired effect.

Ultimately, the program-management challenge – and the value brought by a good systems-of-systems integrator – lies in helping DoD make tradeoff decisions. How can we measure this? The ability to make tradeoffs requires broad access to knowledge, not only on technology but also on military need and relative priority, across all potentially applicable systems and subsystems and all components and specialties. Although this is a demanding challenge, it is true that access to knowledge can, in fact, be measured. The number of systems and subsystems and components and specialties are known (or at least knowable), and whether they *are* known can be documented and measured with considerable precision. As such, by measuring the degree of access to relevant information, it is possible to compare different project-management models against one another.

This ability to measure suggests one possible approach. Stable teams of talented scientists and engineers can be assessed in each of their access-to-knowledge categories (systems, subsystems, components, technologies). Those measures can be both relative (i.e., comparing DoD labs, R&D centers, and private contractors) and absolute (Do we have enough? Is everything covered?). While this approach is input-oriented and assumes that better access to relevant information will lead to better outcomes, it allows for the comparing and relative ranking of competing organizations or management structures, and it also allows comparison over time. Eventually, a baseline standard can emerge.

Based on the premise that the clash of ideas, and the evaluation of tradeoffs among those ideas, really does lead to better solutions, the measures above may also support an assessment of who can do a better job of systems-of-systems integration. By measuring who has better access to knowledge, we can identify who can better foster that clash of ideas and the corresponding tradeoffs. Such a process could move the choice of program management structure from one of emotion and philosophy to one of analysis and metrics. This approach offers promise for such a process.

Organizational flexibility and resilience: keys to a solution

Some direction can also be found by considering what must happen for a program to meet schedule and budget objectives:

- Warfighter needs must be gathered and assembled into a complete, comprehensible specification or a Request for Proposal (RFP).

- Potential bidders must be able first to understand that RFP and then to submit bids that allow fair compensation and that share risk reasonably.

- Government analysts need to compare bids, applying their expertise and experience to identify and reject unrealistic assumptions.

- End users must have input to tradeoffs across capability, schedule and budget.

Once a contract has been awarded and execution begins, design changes must be integrated appropriately. Realistic assessments about progress and potential must be made, and ways found to manage newly encountered tradeoffs. Unanticipated events will happen, and success will hinge on how well the chosen program management and governance frameworks react to the unexpected. The measurement of access to knowledge outlined in the previous section does not help us assess an organization's ability to respond to change; we must seek that elsewhere.

By looking at successful private sector examples, we can see some elements of a potentially successful approach. One typical private sector approach to addressing complexity is to improve the ability of an organization to understand and respond to changes in its environment, by becoming a "learning organization." Such organizations can learn and adapt to changes in the environment and ultimately bring about their own continuing transformation.[4] Successful innovators in dynamic industries – for example, IBM, 3M, Goldman Sachs, and Google – have institutional and organizational structures that enable them to adapt quickly to changing commercial conditions. They can tolerate false starts and the accompanying waste, having honed organizational characteristics that allow them to change course quickly. They devote resources to learning what's happening, pursue what works and abandon what does not, spend less time planning for everything in advance, and not try to execute the plan regardless of what is learned along the way. These attributes amount to making the organization more capable of handling unexpected situations, by accepting that they will occur and trying to make the organization more resilient.

Complexity entails unpredictable, rapid changes. It can be addressed by increasing the system's *flexibility* and *resilience* (F&R), so it can successfully absorb and react to changes, problems and opportunities. We define F&R as the ability to recognize,

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[4] Donald Schön (1973) *Beyond the Stable State: Public and Private Learning in a Changing Society*, Harmondsworth: Penguin, p. 28.

survive and respond to changes. In practical terms, this means the organization must recognize, understand and react to internal and external developments. The organization must be acutely aware, from the lowest to the highest levels, of changes in the external environment (user needs, the operating environment, relevant doctrine, etc.) and the impact of those changes internally and on the program in question. An awareness of the internal environment – the details of the production and design cycle, technological or engineering developments that might threaten budget or schedule commitments, etc. – is also necessary. Managers and employees at all levels must be empowered to communicate their conclusions about perceived changes and the impact of those changes and to take appropriate action to react to the changes.

Flexible and resilient programs must have management and leadership – including political overseers – that is willing to tolerate a certain amount of failure, a certain number of false starts, and spending that sometimes appears to be less than completely efficient. Program management and the accompanying contracting process need to focus on accountability, sometimes at the perceived sacrifice of efficiency. We contend that coping with complexity puts a premium on flexibility, and some sacrifice of apparent efficiency is necessary in order to get greater benefits of on-time and on-budget delivery.

Can the government create such organizations?

Successfully instituting flexibility and resilience will require significant changes in the culture of acquisition and program-management organizations. Training will be needed so employees understand the big picture and can make their piece of the small picture work better. Management needs to cultivate some level of tolerance for error and be willing to grant the necessary autonomy and authority for decision-making at lower levels. Systems across the organization must be designed to allow widespread sharing of information, perhaps even including sensitive data on profitability. The organization must also gather external information and disseminate it widely, to allow the ranking and prioritization of system attributes that allow tradeoffs to be made more easily. An effort should be made to reduce bureaucratic barriers to efficiency, such as extremely tight budget controls or overly stringent documentation requirements. Most importantly, incentives should be aligned throughout the organization to encourage and reward desired behaviors. A model might be the way the military sometimes pushes authority and responsibility down through the hierarchy, with commanders describing their intent and junior officers and troops having some latitude in how they attempt to achieve it, within guidelines.

The attractiveness of F&R attributes lies in their ability to be applied regardless of what overall management approach is chosen. Focusing on F&R in existing organizations is a way to side-step the discussion over choosing exactly the right project management model that would rely more on the private sector, an FFRDC, or a government laboratory (see Box 1, Program Management Models). Traditionally, a management model would be chosen by analyzing the project, selecting a management model, then hoping that the choice was correct. Instead, F&R offers an approach that should work regardless of what challenges are encountered, because F&R is itself is a model of adapting to complexity, of embracing it and being ready for the pitfalls and opportunities it offers.

Box 1: Program Management Models

FFRDC

Federally funded research and development centers (FFRDCs) – which sprang up in the early years of the Cold War – are specially chartered non-profit institutions that receive long-term government contracts to conduct research. FFRDCs cannot compete for production contracts, and the long timeframes of their contracts typically result in low employee turnover and long institutional memory. Prominent FFRDCs in the defense sector include MITRE, the Aerospace Corporation, RAND, the Center for Naval Analyses and the Institute for Defense Analyses.

UARC

University affiliated research centers (UARCs) developed during World War II to explore advanced technologies sponsored by the Department of Defense, primarily the U.S. Navy. There are five officially designated UARCs, including the Johns Hopkins University Applied Physics Laboratory and the Applied Research Center at the Pennsylvania State University. Other organizations – including the Institute for Soldier Nanotechnology (ISN) at MIT – also conduct UARC-like work.

Government Lab

As part of the military's systems commands, government labs provide assistance with systems integration. Government labs are staffed by civil service personnel, allowing for organizational longevity and good customer understanding. Although government labs provide "quick fixes" to the warfighter, this often hinders their ability to focus on long-term research projects. Government labs are sometimes criticized for a lack of organizational independence and an inability to provide the "total package" for systems integration. Examples include the Air Force Research Lab (AFRL) and the U.S. Naval Research Lab.

LSI

The Lead Systems Integrator (LSI) model involves a contractor or team of contractors hired to execute large, complex, defense procurement programs. This model gives the contractor a variety of roles: "requirements generation, technology development; source selection; construction or modification work; procurement of systems or components from, and management of, supplier firms; testing; validation; and administration."[5] Prominent programs managed by LSIs include the Coast Guard's Deepwater and the Army's Future Combat Systems (FCS).

[5] Valerie Bailey Grasso (2009) *Defense Acquisition: Use of Lead System Integrators (LSIs) – Background, Oversight, Issues, and Options for Congress*, Washington, DC: Congressional Research Service. http://www.fas.org/sgp/crs/natsec/RS22631.pdf

Each of the three organization types possesses F&R to some degree (see Table 2, Flexibility and Resilience under Various Governance Models). Let's look at each in turn.

First, FFRDCs and UARCs have proven that they can be flexible in managing technical teams in dynamic environments and sustaining them over time, even when those teams have been challenged with different types of projects that demand a wide array of skills. UARCs and FFRDCs sustain the institutional stovepipe functions needed to house technical knowledge and expertise. They provide the matrixed integration to bring that array of technical knowledge and expertise to bear in a systems-of-systems architecture approach. As a result, they can more easily provide a broader reach across technical areas, integrating multiple disciplines under a single pursuit. This flexibility to reach across disciplines may become more significant in the future, as overall defense missions are clarified in new technology areas. Further, UARCs and FFRDCs have the flexibility to attract and retain top talent.

Several elements make FFRDCs and UARCs particularly resilient: their independence, the absence of even the appearance of conflict of interest, the protection of proprietary information, and the provision of equal access to all potential interested and qualified parties (public and private). FFRDCs and UARCs have a lower rate of employee turnover, contributing to the institutions' historical memory and ability to promise steady configuration-control procedures. However, FFRDCs, with dedicated budget line items, while less driven to take on customers regardless of how their work fits into institutional priorities, may become sluggish or too responsive to the expected answer phenomena because of the line item funding. (This is less true of UARCs, with no dedicated funding line.)

Second, government labs and engineering centers exhibit F&R to a lesser degree. One reason for this is their link to a systems command sponsor, a relationship that sometimes exhibits tension. The lab or center may feel that the systems command ignores their priorities and feeds its own larger goals, while the systems command may feel that the lab or center does the same in reverse, that is ignores systems command goals to keep doing what the lab and its leadership consider more worthwhile. In other words, the systems commands may see labs as less responsive and flexible. This is particularly important if the systems commands rely on their researchers to help them be smart buyers.

Furthermore, systems commands tend to believe that scientists should support their immediate needs for advice on particular acquisition programs and for quick fixes to get equipment working for upcoming deployments, even if the solutions are temporary, non-systematic, and non-repeatable. Both of these pressures detract from in-house lab scientists' ability to pursue long-term research projects.

On the other hand, DoD labs and centers during the past decade or more have actively moved into new partnerships with the private sector. Driven primarily by a need to find additional (non-government) business to finance their workforce and facilities, labs have broken into new areas that are not consistent with their system command’s priorities or with the labs’ prior core competencies. This provides them with the potential for flexibility.

Furthermore, because they are part of the military itself but are staffed mostly by long-term civil servants, government labs possess resilience due to organizational longevity and customer understanding. However, DoD labs are less successful than FFRDCs or UARCs in attracting and retaining top talent because of the constraints of the federal civilian employee rules and limitations.

Third, private companies have, in recent years, led many of the cutting-edge military systems integration efforts, whether individually or in partnerships. Some efforts have been more successful than others, but prime contractors clearly have a base of program management experience to build on. Given that the defense business cycle is affected by the annual political cycle of Congressional appropriations, industry has had to develop the key attribute of flexibility if only to incorporate such considerations into their business. Similarly, flexibility was developed in order to manage relationships with both industry partners and sub-contractors. The ability to attract, retain and manage top talent from relevant technical disciplines also supports this flexibility.

Private companies also possess resilience to a great extent. This stems from a high level of customer understanding. The ability to grasp military jargon and to track various military ideas and doctrinal initiatives is developed intensively, both through internal training and by hiring retired military officers. Furthermore, the need to stay commercially viable provides great incentive to find ways to adjust to changing conditions.

Table 2: Flexibility and Resilience under Various Governance Models

	FFRDC/UARC	Government lab or center	Private contractor
Resilience	▪ Independence (incl. ability to verify performance) and lack of conflict of interest ▪ Ability to retain talent ▪ Work on long-term contracts ▪ Institutional memory	▪ Long-term relationships with customers ▪ Organizational longevity	▪ High level of customer understanding
Flexibility	▪ Technical expertise across wide range of topics ▪ Ability to attract talent	▪ Range of collaborative efforts with academia and industry	▪ Ability to manage relationships with customer as well as with partners / suppliers ▪ Ability to attract talent ▪ Strong (financial) incentive to adapt to changing conditions

Practical matters

Flexibility and resilience are clearly elements of successful management of complexity, and they are available to the government through each of its current models. To be effective, though, F&R needs to be increased at each of the three phases in program development:

Requirements determination: Currently, system requirements, once formalized, are difficult to change. The process of reaching a decision through the Joint Requirements Oversight Council in DoD can take two years or longer, making any system manager (even the Secretary of Defense) reluctant to raise questions that could cause that process to be restarted. Yet, requirements should permit users and developers to be smarter today than they were yesterday. System design goals should be adjusted accordingly. Flexibility in requirements is necessary to promote competition and a better alignment of contracts and resources.

Pre-award (contract preparation): The process of converting requirements into an RFP, running the bidding and making an award must be improved. This pre-award process is the government's way of converting requirements into a solicitation document, then seeking bids from potential contractors. The process includes the scope of work that will be performed by the winning bidders and the criteria for evaluating their bids. It also includes the government's evaluation of those bids and selection of the winner or winners. In recent years, the results of this pre-award process have been less successful than in the past, as measured by the number of successful protests lodged by losing bidders with GAO. In many cases, protests are upheld because of procedural flaws by the government in solicitation, evaluation, and award of contracts. In some cases, good decisions have been undermined by governance failures as simple as inadequate documentation. Process failures need to be reversed as a minimum condition of success in organizing for complex systems. Tolerance for adapting to changing conditions while maintaining compliance with regulations requires both flexibility and resilience and will lead to better pre-award efforts.

Post-award (contract management): The process of managing contracts following award needs to be improved. For complex systems, this post-award process is hard enough even with clear requirements and a pristine pre-award process, because the tasks under contract are challenging and difficult to achieve. Yet the quality and quantity of post-award personnel, the contract administration organizations, has been dramatically reduced since 1990, and the process of restoring them has yet to begin. This is an area where private sector best practices in F&R are most applicable, as government organizations adapt to changes in technology, threats and responses.

Summary

What may be needed, therefore, is a way to tie the underlying DoD skill base to systems-of-systems integration by connecting it to access to knowledge, both current and emerging. By doing so, we may be able to address both our concerns – how do we organize for better management of complex systems, and how do we measure success. Incorporating flexibility and resilience into the management structure will also contribute to success.

Areas for future research

- How to measure flexibility / resiliency?
  - Measures of input
  - Measures of output

  Consider for example SEI's Capabilities Maturities Models (which evolved from software process measures). If the CMM approach can be adapted to cover broader systems engineering work, as is being tried today, we may evolve measures that can encompass the entire systems-of-systems integration. Can we assess components of a systems-of-systems integration approach to derive subsidiary measures that are useful within the management, budgetary, or programmatic time frames?

- What components could we measure? One such component could be subsystem familiarity. Knowledge of subsystems is essential to successful systems-of-systems integration. Surrogate sub-measures for this knowledge could be:
  - the processes for training and educating engineers, scientists, and program managers;
  - the hiring of personnel from subsystem contractors;
  - rotating personnel into other phases of component design and production, etc.

  Somehow, these surrogate measures each seem to miss the mark, but perhaps these together with others could address the overall issue.

- How to institute flexibility / resiliency? There's a lot of business / organizational management literature on doing this at the organizational level, but very little on how to do it at the policy / governance level.

- Are there applicable lessons from how the private sector approaches management / governance of complexity?

Author Biographies

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