Complex Government Technology Development Programs: Meeting the Policy Challenges

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***Abstract*-Government technology development programs are proving difficult to deliver on time and on budget, a consequence of the complexity inherent in both the technology and the acquisition environment. This paper advocates the development of new governance and management models for such programs, as well as new thinking about how to compare these models. It also highlights the need for increased flexibility and resiliency (F&R) within organizations (both public and private) to better prepare them for governing and managing such complex programs.**

I. Introduction

Complex defense and network-centric systems, such as the Army's Future Combat Systems, the Coast Guard's Integrated Deepwater System and the FAA's Next Generation Air Traffic System, are far more ambitious than any previously attempted by the U.S. government. Successfully managing these complex programs is vital, because they are designed to provide the core of many critical future government capabilities and citizen services.

Such systems are difficult to develop and oversee. The programs are designed before the technologies they incorporate actually exist. They are implemented by teams 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 what are often life-or-death situations. This is difficult work. Governance and management techniques struggle to keep up as complexity blossoms, often resulting in blown budgets and missed schedules. Cost and schedule overruns 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.

A recent CSIS book [1] put forward several models for rethinking the policy framework in which complex programs are developed. Yet the fact that problems appear regardless of the program management mechanisms in use implies that the solution may lie elsewhere. We argue that successful governance of complex programs requires the ability to recognize and adapt to the challenges complexity poses.

We posit that government policy makers, in their efforts to select the right model to govern a complex technology development program, should focus less on making the right choice and more on ensuring that whatever option they do select can successfully identify, survive and respond to changes. In any complex program, changes are inevitable in user requirements, program scope, budget, external 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 within a policy framework that embodies flexibility and resilience. We are not recommending a model. Rather, we are recommending an organizational way of life – attributes that an organization must have, if it is to be able to govern and manage complex programs successfully.

This paper describes the challenges complexity brings to government technology development programs, highlights the need for a way to assess and compare governance models, and shows how the challenge of picking the right model can be mitigated by ensuring that the model incorporates 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.

II. 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, it is a fundamental characteristic of complex systems that the interplay of the various elements brings unique additional capability. Therefore, complex systems cannot be deconstructed to their constituent elements; doing so would remove the added value that results when the systems integration function is undertaken.

Historically, there has always been a tension between the increasing complexity of new technologies and the policy frameworks that govern them, yet 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. Most importantly, this government inability to adapt policies and governance mechanisms to innovations in hardware and services often constrains the societal benefits from these innovations [2].

III. 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. Today, complex programs require that many external elements and activities, 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. This integration 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 19th century to the recent Lead System Integrator (LSI) approach embraced by the U.S. Department of Defense (DoD) for some of its major development programs. Responsibility for requirements definition, program management and technical execution has increasingly shifted away from government and toward the private sector (see Table I below). This trend resulted from reasonable efforts to reap the benefits of competition in both innovation and economics.

TABLE I
GOVERNANCE MODELS IN DEFENSE PROGRAMS [a]

	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
Security Environment	Little commercial application of military tech	Some commercial application of military tech Private sector pays better, can be more responsive	Weapons 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 is possible

[a] Source: H. Sapolsky, "Models for Governing Large Systems Projects", in *Organizing for a Complex World: Developing Tomorrow's Defense and Net-Centric Systems*, G. Ben-Ari and P. Chao, Eds. Washington, DC: CSIS, 2009, 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 [3].

Recent experience confirms the difficulty of managing complex system development programs to time and budget. For example, since 2000, the 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. 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, fiscal year 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 military [4].

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 that place new demands on others [5]. That is, while programs go awry for varied reasons, problematic programs have in common their inability to address the complexity challenge effectively.

IV. 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. 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 governance and management challenges – and the value brought by a good systems-of-systems integrator – lies in helping the government make tradeoff decisions. How can we measure this ability? Making tradeoffs requires broad access to knowledge, not only about technology but also about government needs and relative priorities, across all potentially applicable systems and subsystems and all components and specialties. Access to knowledge can, in fact, be measured, though doing so is a demanding challenge. The number of systems, 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 governance and 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 government 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 the comparing and relative ranking of competing organizations or management structures. 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 governance and management structure from one of emotion and philosophy to one of analysis and metrics. This approach offers the promise of such a process.

V. 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:

- User requirements 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 specification or RFP and then to submit bids that allow fair compensation and 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 such approach to addressing complexity is to improve the ability of an organization to understand change in its environment and respond to it by becoming a "learning organization." Such organizations ultimately bring about their own continuing transformation [6]. Successful innovators in dynamic industries, such as IBM, 3M, Goldman Sachs, and Google, have institutional and organizational structures that enable them to adapt quickly to changing commercial conditions. Having honed organizational characteristics that allow them to change course quickly, they tolerate false starts and the accompanying waste. They devote resources to learning, pursue what works and abandon what does not, spend less time planning for everything in advance, and do not 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.

The same is true in government technology development programs, where complexity entails unpredictable, rapid changes. Increasing the system's flexibility and resilience (F&R) enables it to successfully absorb and react to changes, problems and opportunities. We define F&R as the ability to recognize, 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.

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 F&R, 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 F&R will require significant changes in the culture of acquisition and program management organizations. Training will be needed so employees understand the big picture and 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, including possibly sensitive data. 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.

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 the "perfect" management model from among the private sector, a Federally Funded Research and Development Center (FFRDC), University Affiliated Research Centers (UARCs), or a government laboratory. Traditionally, such a 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.

Each of the three organization types at the government's disposal possesses F&R to some degree (see Table II). 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 were taksed with different types of projects demanding a wide array of skills. UARCs and FFRDCs sustain the institutional functions needed to house technical 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 government 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 specific government sponsor, a relationship that sometimes exhibits tension. The lab or center may feel that the sponsor ignores their priorities and feeds its own larger goals, while the sponsor may feel that the lab or center does the same in reverse, that is, ignores sponsor goals to keep doing what the lab and its leadership consider more worthwhile. In other words, government sponsors may see labs as less responsive and flexible. This is particularly important if the sponsors rely on their researchers to help them be smart buyers.

Furthermore, government sponsors 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. These pressures detract from in-house lab scientists' ability to pursue long-term research projects.

On the other hand, government labs and centers during the past decade have actively sought 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 traditional 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, government labs are less successful than FFRDCs or UARCs in attracting and retaining top talent because of the constraints of the federal civilian employee rules.

Third, private companies have, in recent years, led many of the cutting-edge government systems integration efforts, whether individually or within 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 government 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 government jargon and to track emerging policies and doctrinal initiatives is developed intensively, both through internal training and by hiring retired government officials. Furthermore, the need to stay commercially viable provides great incentive to find ways to adjust to changing conditions.

TABLE II
FLEXIBILITY AND RESILIENCE IN VARIOUS GOVERNANCE MODELS

	FFRDC/UARC	Government lab or research 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

VI. PRACTICAL MATTERS

Flexibility and resilience are clearly elements of successful governance and 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:

A. Requirements determination

Currently, system requirements, once formalized, are difficult to change. The process of reaching a decision can take several years, making any system manager (even if at the cabinet secretary level) 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.

B. 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 the 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. Minimizing such process failures is necessary for resiliency. Tolerance for adapting to changing conditions while maintaining compliance with regulations requires both flexibility and resilience and will lead to better pre-award efforts.

C. 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.

VII. SUMMARY

Innovations in products and services co-evolve alongside new forms of governance, management and organizational structures. However, the recent track record proves that the government's existing tools no longer suffice for large-scale, horizontally integrated complex programs, as many of these programs exhibit cost overruns, schedule slippages and other developmental setbacks. This is the result of two parallel trends: the government's decreasing ability to manage large technology development programs in-house (due in part to a stagnation in thinking about management models, but also to the government's outsourcing of engineering and management tasks), and the dramatic increase in the complexity of these programs.

Pioneering new policy and governance models is only part of the answer, and one that is now beginning in earnest via various new research efforts. We propose two other elements of the solution. The first is tools for comparing the various new governance and management models that are currently emerging, such as measuring access to information and knowledge. The second is tools for offsetting the risk inherent in selecting any type of governance or management model by embedding the ability to adapt to changing circumstances into the organization. Increasing an organization's flexibility and resilience to the uncertainty and change inherent in complex programs increases an organization's capacity to manage those programs.

What is now needed is for governments to play a greater part in developing and implementing new knowledge on new governance models, ways of comparing them, and ways of increasing organizational F&R. While there is much to be learned from the private sector, we cannot afford to be dependent on it for the next generation of governance and management innovations.

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