The Changing Nature of Systems Engineering and Government Enterprises: Report from a Case Study Research Effort

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I. Introduction

Work in the 21st century, and the organizations within which work takes place (including the networks of relationships that complement or replace formal organizations), has been changing rapidly (e.g., Barley & Kunda 2001). As has happened frequently in the study of organizations, the world of practice leads the world of theory. While organizations struggle to survive and thrive in this post-bureaucratic world, organization theorists struggle to theorize about, support, or even help lead these changes.

In this paper, we examine the changing nature of systems engineering work and, in particular, how The MITRE Corporation is confronting the challenges of expanding its role and capabilities to deliver what it calls "Enterprise Systems Engineering" to its government clients[1]. Systems engineers exemplify technical knowledge workers whose work is expanding beyond the traditional skills and habits of thought developed through their disciplinary training (cf., Davidz 2006). Changes in technology, systems acquisition

[1] MITRE comprises several Federally-Funded Research and Development Centers (FFRDC) which are chartered by sponsoring departments or agencies of the federal government of the United States, such as the Department of Defense, the Federal Aviation Administration, and the Department of Treasury.

practices, and enterprise structures are challenging systems engineers to expand their roles and capabilities to manage the boundaries among technological systems and organizations of many sizes and types (e.g., government customers, systems integrators, suppliers, end users). Systems development takes place in an ever more complex environment of inter-organizational enterprises where implementation increasingly catalyzes enterprise change and demands greatly expanded and often unrecognized roles beyond that of technical expert or project manager.

Since MITRE's early days, when there was more emphasis on designing and developing custom-built systems for individual agencies (commonly referred to as "stovepipe" or "silo" systems), MITRE has had to face two main expansions of complexity relative to its engineering work activity, the first technological and the second organizational. First, under the rubric of "information superiority," a shift from custom-built systems to the use of information technology (IT) for communication, command and control systems (referred to as "software-intensive systems") has been going on for over twenty years. Systems engineering, a discipline traditionally oriented towards design, development and testing of standalone weapons and radar systems, struggles with geometrically cascading interdependencies driven and shaped by IT (Bourgeois & Eisenhardt 1988; Leveson 2004). The upstream suppliers (cf. Davies 2003; Hobday, Davies, & Prencipe 2005; Pavitt 2003) of IT are less likely to be large system contractors and more likely to be commercial product vendors selling commercial-off-the-shelf (COTS) technologies. Second, MITRE's downstream customers are less likely to be single organizations looking for standalone ("stovepipe") systems and more likely to be multiple organizations seeking inter-organizational networked systems. In a recent survey of senior systems engineers at MITRE, the organizational and political aspects of major projects are considered to be at least as challenging as the technical aspects (Rashid 2008).

Our ideas emerge from five empirical case studies of systems development and enterprise change involving clients of The MITRE Corporation. Our grounded, socio-technical approach considers both the work activity and the practical implications of the technologies that comprise much of the work substance and product. Through focusing on the work of systems engineers, we identify patterns of change and development in the nature of work, organizations, industries, and institutions. Our objectives are to empirically ground and enrich social science theories of technological and enterprise innovation with data about the work (Barley & Kunda 2001; Dunbar & Starbuck 2006) as well as to transform practical field experience into useful and transferable knowledge for systems engineers and other agents of change and for organizations like MITRE that are developing new capabilities in the post-bureaucratic world of knowledge work.

II. Literature Review

Systems Engineering

Systems Engineering began as a sub-discipline of engineering during the late 1940s and 1950s when the development of weapons systems and aerospace were getting beyond the scope and tools of separate engineering disciplines (Johnson 2003; Sapolsky 2003). By offering the label of "system," the focus was placed on the technical system being engineered, such as a missile or airplane, rather than on the component pieces that were the responsibility of discipline-based subteams and subcontractors.

The field of Systems Engineering has continued to grow as more large-scale systems are developed in military and civilian applications. The term "system-of-systems" is routinely applied to distinguish this work from typical systems engineering (Keating, Rogers, Unal & Dryer 2003). As corporations outsource many parts of the supply chain, some have taken a specialized strategic role as "systems integrator." Boeing for example no longer "makes" planes but rather does overall design and some assembly, with manufacturing technology increasingly outsourced. MITRE provides primarily systems engineering services (systems architecture, oversight of suppliers), particularly around new information technologies but increasingly around broader systems-of-systems. MITRE has identified "Enterprise Systems Engineering" or "Advanced Systems Engineering" as a set of skills and capabilities to provide clients with systems even more complex than systems-of-systems.

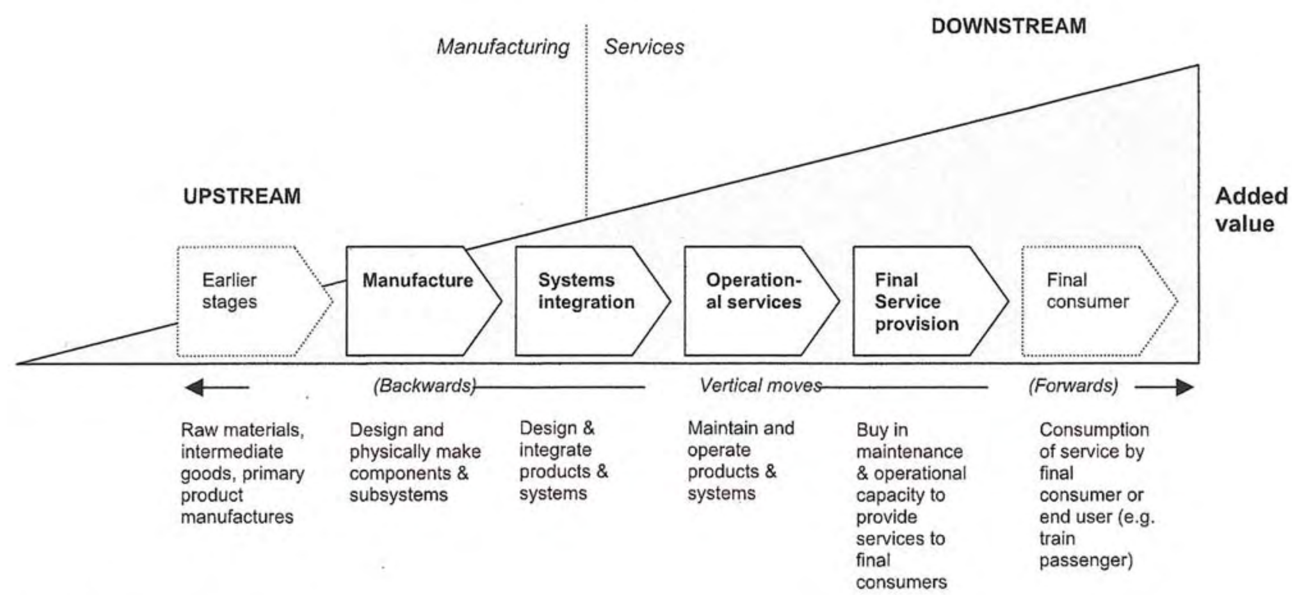
The major activities within systems engineering are systems analysis, acquisition and supply, project management, system design (requirements and specifications) and integration, implementation or transition to use, and technical evaluation (EIA/ANSI 632, *Processes for Engineering a System*, 1999; Johnson 2003:36). The most recent and widely-disseminated definition of systems engineering says that

> Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems… Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs. (INCOSE, accessed 2008, http://www.incose.org/practice/whatissystemseng.aspx)

Taking a resource-based view of the firm, Hobday, Davies and Prencipe (2005) argue that systems integration (a component of systems engineering) is a strategic core capability of contemporary high-technology firms, crucial for the development of complex products and services such as telecommunications networks, aircraft, etc. In commercial enterprises, systems integration is usually accompanied by strategic management of component and subsystem supplier networks and/or financial and operational services, although this is less true in MITRE's case.[2] Davies (2003) and Hobday, et al. (2005) also note that systems integration can shift up and down the value stream depending on the company's traditional competencies and the particular product under development.

Although systems engineering is taught in many universities, there are few places to learn more advanced systems engineering skills in academic settings. Davidz (2006) studied how systems engineers learn systems thinking skills. The primary source was through work experience, specifically involvement in and leadership of increasingly complex projects. A second source was life experience outside work. Academic training can support this kind of skill development but cannot be the primary source, because this type of knowledge is context-rich and practice-based. The formal tools of traditional systems engineering, such as requirements definition, proposal solicitation and evaluation, source selection, program management, integration testing, risk management, and configuration management presume a

[2] This difference may help account for many of the difficulties that MITRE's ESE efforts are encountering (see Practical Implications section below).



Source: adapted from Davies (2004)

The value stream in high-technology capital goods.

Figure 1 (based on Figure 5 from Hobday, Davies, & Prencipe (2005: 1134)

degree of predictability and hierarchical authority that are not readily available in government enterprises.

Government Enterprises

Government enterprises are the clients of MITRE and the sources of our case studies. By "enterprise" we refer to sets of organizations brought together to produce a product or service on a large scale. Swarz and DeRosa (2006, p. 3), in a MITRE report, define enterprise as

> a collection of systems whose operational capabilities are inextricably intertwined with considerations of people, processes, and technology, whose boundaries are often imprecise, and which can often be characterized by a set of special, additional properties, such as emergent behavior, non-determinism, and environmental dependencies.

Their definition is certainly complex and signals the cross-boundary nature of enterprises. Whereas government (and the corporation) has traditionally been organized in separate activities, there is an increasing demand and mandate (from Congress and/or the President) to work across organizational boundaries for system-wide outcomes. More than a dozen civilian agencies have been consolidated into the Department of Homeland Security. The military services (Army, Navy, Air Force, etc.) have also been pressured to collaborate as a single "Joint" force, and are now dealing with Department of Defense mandated "Transformation of Force Structure" in addition to an ongoing transition toward "net-centric operations." The Intelligence Community is undergoing a major reorganization. The Federal Aviation Administration faces daunting challenges in managing the National Air Space (NAS) due to sizable increases in both diversity and volume of air traffic. As government agencies strive to operate as integrated enterprises with common purpose, their technological systems (information, communication, etc.) and administrative systems (acquisition, costing, etc.) are also changing and sometimes leading change. Our MITRE case studies illustrate the process of merging separate legacy systems with new and more integrated technologies to serve enterprises.

Government enterprises in the US face particular structural challenges arising from their workforces, culture, and business practices. A majority of personnel in both the civil service and military command are long-term (lifetime) employees enjoying considerable job security. At the same time, top managers of government agencies are more often in office for only limited durations, either as political appointees or due to military career-path rotations, therefore having few incentives for long-term commitment to a specific agency. Thus, government employees, faced with pressure from the top, may find it expedient to simply resist change by waiting for leader-initiated changes to "blow over" (as leaders leave). There also is no culture of bottom-line profit to create a shared goal for middle managers and no single leader to unify separate agencies (Presidents have not typically involved themselves in this way). As a result, members of the workforce sometimes experience an unpredictable stream of leadership changes, budget cuts, and program cancellations.

There are comparable challenges in the institutional arrangements for "acquisition" or the contractual, legal, and regulatory arrangements for how new technological systems are to be funded, built, and fielded. Tightly constrained budgetary cycles are insensitive to emergent requirements and contingencies. Fast-paced streams of technological innovation clash with slower-paced integration tasks (cf. Ancona & Waller 2007) to integrate without risking current functionality. Budget processes require strict cost accountability, especially according to Congressional districts, which encourages competition among suppliers and localities; the result is stovepipe technological systems and fiefdoms with continual power struggles, rather than functionally integrated enterprises. Political conflicts involving information systems are common (Feldman & March 1981) and the inherent relational tensions of coordinating technological design across organizations (O'Sullivan 2006) are accentuated at the enterprise scale. Stakeholder groups whose cooperation is essential to the enterprise routinely mistrust and misunderstand each other: there are huge differences in language and philosophy between technologists, managers, policymakers, and members of the civil and military services (customers/users) (Schein 1996).

The Role of Technology and Systems Engineers in Enterprise Change

Systems engineers are in some ways well-equipped and in other ways ill-equipped to act as change agents in government enterprise transformation. Technological seduction (Schein, 1996) is one way to begin large-scale change, i.e., by building a new information system or other process that will act as a fulcrum for change in behavioral routines. If legacy systems that could not talk to each other can now share information, more than data may be shared: terminology, mindsets, goals, and attitudes begin to shift as well (Malone 2004). The technology can be the "tip of the spear" in promoting enterprise integration, and the technologists appear to be wielding that spear and to be granted legitimacy or status because of their role in producing the technology. MITRE's specialty of systems integration in particular is growing and emerging as a key vehicle for organizing networks of production within and across the broader society (Hobday, et al. 2005).

Engineers in general, whether through temperament, selection, or acculturation, deeply believe in the ability of technology to solve problems. They love a challenge and jump readily into problem-solving mode to find solutions. They are bold, if not immodest, in offering solutions. However, engineers less often understand the human and organizational aspects of these problems. Designers may assume that users will think and act the way an engineer would and not listen sufficiently to users (or believe they know better). A functional improvement that "solves the problem" may be resisted because it undermines the capabilities or status of particular groups. Emergent social behaviors in reaction to technological change (Barley 1986; Orlikowski 1992) render traditional planning tools ineffective (Suchman 2007). It is a rare engineer who is also politically-savvy and organizationally-adept. Yet that is exactly the combination of skills needed for enterprise systems engineers, i.e., to combine traditional systems engineering tools and skills with broader systems thinking that includes both technical and socio-organizational systems and the interpersonal and political skills to persuade and build trustful relationships among a wide range of stakeholders.

III. Methods

In consultation with MITRE management, five technology development programs were identified as potential subjects for in-depth study and analysis via case studies. The case study approach (Hancock & Algozzine 2006; Markus & Lee 1999; Yin 2003) was selected to provide a narrative history of the program (including major stakeholders, timeline of major events, key participants, important decisions, and key outcomes) and to explore the multitude of factors that were thought to be potentially relevant in understanding "complex social phenomena" (Yin 2003, p. 2) in a technical environment. The selected projects had an enterprise component and were to be actively under development. Program durations range from just a few years to almost 30 years of existence.

The major data collection was through semi-structured interviews, with a common protocol. Individuals were nominated by management as possible interview subjects based on their current or past affiliation with the project. Three to six individuals were ultimately interviewed for each technology program; their identity was kept confidential. Interviews of 60-90 minutes duration were conducted in a conference room or in the individual's office. A MITRE engineer on our research team was present to ask the questions, pursue any follow-up questions, and to provide any technical insight that might be required during the interview session. One to three note-takers were present or were connected to the interview session via teleconference call. Transcribed interview notes, in conjunction with project documents, direct observation, and other program-related materials, were sources used to write and develop the case studies.

Written case study drafts were provided to all interview participants for their review and feedback on accuracy, completeness, and the general tone of the content. Since direct quotes were sometimes used in the case study write-ups, interviewees were allowed to request that quotes not be used or be modified to provide greater anonymity. Revisions were made based on the feedback received and the cycle was repeated until we reached consensus among participant and review by the technology program managers and MITRE's Engineering Council and senior management.

IV. Analysis

Due to confidentiality concerns, we cannot describe each case in detail. (A brief summary of each case is provided in Table 1.) Rather, we assemble our observations and analyses into two major sections corresponding to the challenges MITRE faces in developing Enterprise Systems Engineering: integrating changing technologies and systems and satisfying changing customer requirements.

Table 1 – Brief Summaries of Case Studies

<u>Operations Planning Tool</u>

Two separate, competing systems aimed at modernizing the software components for joint operations planning were merged. One was a decade-long program that focused on incremental improvements to and upgrading of the existing legacy system through a highly structured engineering process. The second used a more revolutionary, or "remove and replace," approach based on the agile prototyping methodology to quickly develop new components. It worked closely with operators to continually refine requirements and update system capabilities through "revolutionary" improvements rather than systematic upgrades. User feedback was the primary source of feedback, rather than the traditional development and acquisition process. Similar operational challenges were faced by both approaches, but were addressed with different contracting approaches with differing stakeholders, goals, timelines, incentives, and success metrics. A blended approach promised the benefits of both approaches without the limitations of either. However, different subcultures built on distinctly different engineering approaches have made it difficult to develop a common set of values to guide development. These contradictory models have lead to "opponents competing rather than collaborating" in creating a cohesive enterprise that is focused on overall project success.

<u>Intelligence Information System</u>

The Intelligence Information System was created to support the communications and information needs of the military services and their major components. Using a distributed, or decentralized, approach, major components were responsible for producing and maintaining data on a particular area of responsibility. Further, each component had control over its own budget and had the flexibility to pick its own hardware, software, and data structures, creating the tendency to focus on local needs and requests. A recent reconfiguring of the larger organization has occurred to focus on developing a globally-consistent, standardized IT enterprise with a centralized primary budget and planning authority. Globally-synchronized data support centers have been developed to support access, mobility, world-wide login, a common analytical data set, enterprise storage, and failover and disaster recovery capabilities. A standardized approach was used to support consistent e-mail, desktop services, applications, and tools. Continuous promotion of the centralized approach has been instituted with on-going training underway.

<u>Linking Technology</u>

The Linking Technology was established in the late 1990s to address challenges in tactical operational communications and coordination. The goal was to develop software and hardware systems to support high capacity, highly networked, secure wireless communications that would be interoperable, affordable, and scalable. The program underwent a major reorganization in 2006 and the initial operational requirements have been approved.

Automated Information System

The Automated Information System (AIS) was chartered to provide an integrated set of services supporting consultation, command, and control across global operations. Initially created to integrate land and maritime information systems, AIS is now tasked with the technical integration of a large number of legacy systems with pre-existing sub-projects, phases of projects, and fielded prototypes into a system that is both coherent and flexible. Therefore, the program development strategy is not a "big bang" strategy, but an evolutionary one that is tied to the history of the international organization itself. A range of enterprise systems engineering practices are being instituted. The acquisition process is being re-defined with the intent of improving how it acquires (sub-)systems. To ease interoperability issues, an emphasis is now being placed on services rather than components. The management and coordination of both external and internal stakeholders is normally well managed; management of the technical issues remains problematic. Bids have recently been sought for a new contractor to handle program management and implementation. Many were optimistic that solutions will be found because processes in this international organization have worked historically.

Program Coordination and Development

An aging infrastructure and a projected two-to-threefold increase in system demand lead to the creation of a Program Coordination and Development Office to coordinate the efforts of six existing federal agencies and the White House to address these system needs, with one federal agency assigned to oversee the creation of the system plan. Industry and academia later joined the effort. Safety, efficiency, quality, affordability, scalability, variability in equipment and participation, security threats, and an increasing concern for the environment also contributed to the complexity of the requirements for the evolving system. Leveraging existing technology and infrastructure is important. Emerging technologies and the ability to integrate data streams from multiple agencies and sources for improved situational awareness and global operations provide a glimpse of what is possible in the future. Different stakeholders have conflicting agendas and perspectives on what is of highest importance and is affordable and reasonable. Although mandated by Congress, achieving the goals of this development program in the projected time-frame will be difficult. However, some recent and significant progress has been made.

Integrating Changing Technologies and Systems

Virtually all of the enterprise systems engineering programs we studied encountered engineering management challenges regarding the integration of technologies at different stages of development. In the technology dimension, this challenge manifests primarily via concerns over establishing and maintaining interoperability across legacy systems and with new innovations, so that data and communications can proceed across systems in a way that is transparent to users: "Basically its migrating legacy applications, getting rid of some things, adding new ones." [P47:2][3]

With the advent of networking technology, many formerly standalone systems associated with separate government agencies are now being interconnected to support flows of information between (formerly separate) agencies. This interconnection is not a simple process and the change is not occurring overnight. Much of it involves creating new boundaries around collections of legacy systems under a new program identity, and then integrating newly developing technologies and systems into the mix.

> Part of the strategy is naming. People get used to a name and what it means and its scope and how to communicate in their … environment. [Program] has been around 4-5 years. [Program] is not a big-bang type of program, it is evolutionary. Didn't start from green field, started from existing baseline. Existing capabilities at operational command were isolated, developed capability. Headquarters evolved over time to more integrated. [P51:1]

Traditional systems engineering methods for achieving interoperability and avoiding redundancies rely on formally structured processes for requirements, design, development, integration, and testing. However, in larger enterprises, different systems and technologies are evolving at different rates, requiring integration at different stages. As one interviewee noted:

> [We are currently at] all different stages. This is a rolling program of all these different capabilities. Some have been signed off and are being deployed. Some already in use. Some deployed only one place. A big transition management program. Training, interoperability within and external to [Organization], consistent with national security problem. Many moving parts, [which] constantly move. People tend to look at a program as static. [This program] is constantly moving.

[3] By convention, "[P47:2]" and other similar annotations are indexes to passages and/or paragraphs within the interview transcripts.

[P53:1]

> Applications have to be developed by industry in netware environment; they can't be developed in isolation. If Company A is developing a stovepipe application (what it is, in reality), if there are about 20 of those, [then there are about] 20 dissimilar tools which don't come together as a toolkit. They are at different stages [of the life cycle], some embryonic. They/we will encounter requirements nobody indicated, new techniques, tools, the platform [operating system] they're riding on will change. (e.g. XML is evolving, several different paths possible). Always the one that compromises us is security/ info assurance. And strategic partnerships are not under our control (e.g. Microsoft). [P48:4; P49:9]

While planners are trying to lay the groundwork for future integration challenges, the technology keeps changing. "The [linking technology] we're delivering is already out-of-date, before it's delivered. You're always chasing what the [linking technology] should look like." [P39:10] Another project interviewee stated, "Operationally, it is difficult to predict… The network could be really shaken up in the future because you don't really fully know how it's going to be done." [P40:13]

Systems Integration Management Practices

How then are systems engineers managing the job of system integration? At a basic level, engineers rely heavily on schedules and other boundary objects (Star 1989; Carlile 2002) detailing all activities and tasks that affect interdependencies between components, and adhere closely to these. Changes are typically authorized and processed through some kind of release authority such as a configuration management board.

> Integrated schedules which list all activities needed and a set of tasks which we adhere to. Configuration management board where we don't release anything without approval. Manage the process. We rely on an initiative or other providers to build products - we do integration. We really work in integration - worry about touch points, sharing drawings, threads to show what will happen. We need to share info. Architecture/system diagrams to show this. Diagrams to monitor and configure activities. [P3:2; P4:5]

One particularly successful strategy for integrating such information systems appears to be provisionally accepting large numbers of new candidate technologies, testing them against a baseline, and then moving ahead with those deemed successful. This is usually carried out as an iterative process extending over multiple years and called a "spiral development" model.

> Unlike [the old] waterfall methodology, they divide the system into smaller components, and develop and procure them separately. The way I describe it is as about 100 spiral development projects that magically integrate into one system. … [They are at] different stages and levels of complexity. My fear is they have different reference architectures which will probably be incompatible. Kind of a mix of legacy systems and new. [P47:3]
>
> Strategy is to experiment with technology capability and process to further command and control process and systems. Procedures I work is 2 year cycle for new initiatives. Scale down and sort through them - down select - to find number that meets set of criteria of agenda set by [Chief of Staff] of [Military Service]. Build up experiment in 3 spirals over 12 months, then [MainEx]…
>
> *Spiral 1* is demos of some level of completion of initiatives.
> *Spiral 2* we've integrated systems, and working on training plan (how would you use my plans and initiatives), practice executing a mission (400 people at [military base]) training them to use the tools
> *Spiral 3* initiatives are operative now at 90-100% complete. Training refined. Dress rehearsal.
> *MainEx*: simulations and aircraft really flying. Look at capacity and processes and personnel. Evaluate. [P3:7]

Engineers are also shortening projects and contracts as adaptive strategies.

> They are following an evolutionary approach in which they're breaking the larger set into sub-projects and phases of projects. They are shortening the time to avoid requirements creep and are using a spiral development approach… Shorter projects timelines helps to deal with changing constraints and changes in national policies. They are willing to cancel or change projects. Contractually, they are operating on task order contracts, which allow them to adapt to changes and allows to multiple exit points where they can decide whether to renew the contract. [P52:5]

One other earnest effort to rein in this task in a manageable fashion is the strategy of hiring a Program Management and Implementation Contractor (PMIC). This has been tried on a number of large programs and it does to some extent address the "multiple stakeholders with competing agendas, no one leader effectively in charge, and no agreed upon metrics for success" – a PMIC is a leader effectively in charge – at least in name, at least for a while (until major changes come along which are outside the scope of PMIC's formal responsibility).

Satisfying Changing Customers and Requirements

Engineering Management Challenges

Accompanying the technological push from suppliers, systems engineers feel pulled in multiple directions by customers in achieving requirements definitions. Increasingly government agencies are seeking to coordinate and consolidate their efforts as *enterprises* that provide government services, using new technology as an occasion for or a means to coordinate. Rather than a single hierarchically-organized customer as in traditional systems engineering, enterprise systems engineering programs are therefore confronted with diverse and competing customer segments.

The first customer-side challenge for enterprise systems engineering is that there is rarely a single individual in charge of the entire enterprise who can mediate differences among the stakeholders or dictate final decisions. Although government organizations sometimes have stable leadership, more often political appointees (and others) occupy their positions for a 2-to-3 year period before moving on to other jobs. This is enough time to plan for and start a transition or new program, but rarely enough time to complete it, leaving it for the next individual who brings their own agenda, goals, and new programs. For example, "I put a significant piece of the blame on him, I don't know where he went -- if you have short timers in those slots and they want to make their mark -- he pushed a lot of policy one worse than the other." [P42:10]

Along with changing leadership within organizations is the division of interests within and between organizations. It's not surprising to hear that different branches of the military have their own way of doing things and therefore resist creating a unified system that would change their own ways of working:

> Customer base - decomposed into air, land, maritime. Commanders want interoperability. To become streamlined, need to force standardization onto people who don't want it. I want to give them something they don't know, but will want in the future. [P53:8]

But there is also considerable variation within organizations: "[Project] runs as part of somebody else's system… without process, have to figure out what they are doing (8 different ways just within [a Military Service]).” [P40:8]

Evident to some degree across all the cases is a major tension between organizational efforts concerned with long range future planning and innovation (R&D) on the one hand, and those efforts primarily concerned with satisfying current operational needs on the other hand. Supporting the former are senior officials primarily focused on long term capabilities and/or interested in establishing (or enhancing) their reputations as innovative leaders (especially under the “information superiority” banner), along with technology vendors and others arguing that government investments in innovative technologies are crucial drivers of the country’s economic engine. Supporting the latter are people working in the field using the current (legacy) systems who are more often concerned with getting their jobs done (e.g. fighting and winning a war) than experimenting with not-yet-fully-stabilized new technologies. Once a new technology has met with user acceptance in the field, the same end users are often only interested in incremental improvements. For example,

> …within the [Military Service]. There are loosely two camps. One camp tend to emphasis leap-ahead capability. Their focus is on the 15 [units] to be fielded beginning in 2016-17. The other camp tend to emphasize more rapid fielding across the broader force (e.g., lower-cost, good enough capabilities). Their focus was on the other 200+ modular force [units]. [P63:1]

Not surprisingly, maintaining control over the requirements process is nearly impossible as each customer group pushes for its interests and desires and (given the timeframe for large projects) changing technologies lure customers into escalating demands. For example, in discussing tensions over requirements, one interviewee referred to “the usual ‘food fight’ with user community about what will meet their expectations.” In discussing the overall planning process, another interviewee said, “had the Enterprise community understood the scope of the endeavor, we never would have embarked on it with the framework we did. We had a schedule and cost estimates that are ‘silly’, unrealistic, when one understands the scope of the activity.” [P7:17] Requirements churn as technology and strategy shift over time: “About two years later, with net-centricity, goals morphed, to support advanced capabilities, mainly in [linking technology]. To do everything for everyone.” [P43:1] “Building based on requirements today, to be implemented in 5-6 years from now…. It’s not (been working), and I don’t see us changing the paradigm.” [P39:12]

A third challenge for managing these projects is that government organizations have few bottom line measures (for-profit organizations can at least measure profit) to drive improvements in efficiency and effectiveness and to stimulate coordination with other related organizations. Many outdated institutional routines which used to facilitate long range planning and budgeting are not only still in place but still legally mandated (something which the engineers have no control over whatsoever). Improvised solutions and processes sometimes degenerate into a free-for-all with the strongest political and/or budgetary muscles winning.

> Original requirements were very ambitious… do everything for everyone and in a short time frame. Had such good top-cover that no one could say 'the Emperor had no clothes.' [P43:1]
>
> [Customer] was an 800 lb. gorilla, enjoyed senior level support. When [Customer] says program will suffer without [Program], [Program] gets support… not resource-constrained. [Customer] is not driven by [cost/benefit analysis]: 'Capability-be-damned—don't bother me with the bills!' [P43:1]

Adaptive Engineering Practices

To deal with these evolving complexities, engineers are developing several adaptive engineering practices. However, these are inventions and improvisations, as one interviewee offered: "Trying architecture, requirements, specs. People are already building things... trying to capture that, and see if it works. Other things start clean. So, we're a little broken in my mind." [P39:6] "It's broken, but not sure that it can be done in any other way." [P41:4]

More intensive user involvement seems to be important: "Ad hoc process… requirements 'discovered' through frequent user interaction." [P5:4] But there is a tension associated with placing advanced prototypes in front of end users. On the one hand, users often want what they see, even when the prototypes are not truly functional (the software/IT community refers to the *Wizard of Oz* epithet, "Pay no attention to the man behind the curtain!"), which leads to 'requirements creep'; but otherwise users, especially warfighters in the midst of combat, may refuse upgrades with inevitable glitches and problems that jeopardize their current operational mission.

From the perspective of keeping operations going, approaches such as "interim solutions," fielded prototypes, and service-oriented architectures are becoming the norm, with integration "successes" emerging out of orchestrated field "experiments." "Many others feel that as well, and are pursuing alternative interim solutions (they use the term 'interim' to get it approved)." [P43:1] But this is a new set of skills for engineers and managers:

> We're trying to get interfaces on change control, so we drew a line around our stuff, created a boundary so now instead of development, we're now participating in management of boundary. So if your stuff works we'll use it, great. If not, sorry, we can't work with you. So we're more management activities than engineering design activities. A good engineer has skills for both, but probably an engineer feels more worth if working on design and engineering of new capabilities than on plumbing. [P1:6]

IV. Discussion

Our results demonstrate that the work practices of systems engineers are coming under increasing pressure from ever more complex projects, rapidly-shifting technology from suppliers, and conflicting demands from customers who want new functionality and interoperability without giving up their current systems or experiencing interruptions that challenge their current mission. Systems engineers are responding with more intensive use of existing tools, such as budgets and schedules, but more importantly with evolutionary, adaptive approaches, increased customer contact, and improvisation. They are moving towards the 'bricolage' approach to technical entrepreneurship (Garud & Karnoe 2003). At an organizational level, MITRE is supporting this research to bring together the lessons learned from this decentralized activity and determine how it can build capability for serving customers.

We begin the discussion with an explication of three issues that have emerged from the results. True to our focus on the work of systems engineers, the first issue is that among our five case studies there are two major kinds of projects that unfold differently in terms of the role of technology, consensus building, and timing. We then consider the omnipresent issue of centralizing vs. decentralizing planning and control. Last, we look at the habits of thought that underlie systems engineering skill sets. We continue the discussion by highlighting the contributions that we hope to make to organization theory and MITRE's practice. We close with a discussion of the limitations of our research and the need for further study.

Two Kinds of Programs

Looking across the five cases, there is a distinction between programs primarily chartered to develop a specific new technological capability – especially when it is intended as an integrating device across diverse and previously disconnected organizations – and those primarily intended to update and integrate an information system comprised of a broad range of legacy and new technologies for a particular operational community. Our interpretation of these kinds of projects is that the former is a strategy of using technology to lead community development, in short, to get disparate user communities to work together around the new technology. In contrast, the latter projects have technology following the needs of an existing user community.

From our small number of cases, we observe that projects that emerged around a voluntary federation of organizational units present a *relatively* smooth transition to a stable set of requirements and relatively more successful project results. Although the engineering challenges of keeping up with rapid changes in available technologies and making them interoperate are daunting, they are still of a routine nature for systems engineers. In contrast, managing diverse customers and fluid requirements is not within the skill set of most systems engineers. One of our cases that we and our interviewees consider successful is from NATO and primarily based on publicly-available data such that it warrants a summary discussion.

As an international political and military alliance, NATO has had to address management of political differences from its inception. Rather than use "C2" for "Command and Control", NATO uses the acronym "C3" to signify "Consultation, Command and Control"– where the "Consultation" reflects concern with political rather than strictly military missions. The checks and balances of the consensus decision making process, with attention to economic benefits as well as technical rigor, and each contributing member nation having a vote, seems to be a workable solution to avoid later disagreements.

While there are inherent tensions, explicit recognition and legitimation of these tensions via organizational structures and policies may facilitate productive approaches to resolving them. For example, the explicit chartering of formally distinct organizational units for managing operations and transformation may bring tensions between stability and change into the open where they can be addressed in a productive way. Similarly, a “host nation” policy which explicitly acknowledges the economic benefit awarded to participating nations and provides a channel for maintaining equity around the awards, may serve to stem the tide of conflict that would otherwise emerge. In short, conflict management is routinized and placed early in the process instead of being ignored and allowed to emerge disruptively later on.

Perhaps the most significant aspect of NATO’s approach to systems engineering, particularly systems integration, is the *Capability Package* process. The Capability Package unites financial, technical, and organizational – including inter-national – dimensions of an enterprise in a single process. It is an agreed-upon process that initiates funding and facilitates budget planning, placing financial responsibility within a single funding vehicle and a specific organizational process. For the technical dimension, the Capability Package affords traceability of requirements, is used to validate requirements for a contractor Statement of Work (SoW) and supports “trace back” during the testing phase and/or when a project is no longer needed. Thus, there is a consensus on the process for managing change around both innovation and implementation, and it generally works.

In a different case that involves a more stable user community, it is instructive to examine how that stability was facilitated. One individual in particular was repeatedly mentioned as perhaps the single most important linkage in creating and maintaining both technical and social connections across a globally-dispersed system. He worked to “MITREize” people to make sure they understood the MITRE approach before they were sent into the field to work in this environment. Personal relationships were created and developed through regular contact by phone, and he moved people around to different positions in different locations to create the right fit. Personal visits to maintain eye-to-eye contact were also an important component in building and maintaining trust. He created both a leaders conference and an annual worldwide technical conference to share information and ideas for this global IT environment. These were intended as free-form discussions on hot topics and new technologies by intellectual leaders in the community, regardless of position, and they continue to this day. The early years of this IT environment were noted as being especially exciting, fun, and challenging while collectively solving problems. Even before the advent of e-mail, people were on the phone with one another to discuss ideas, inform each other of new technologies, and coordinate system design and technical development.

On the other hand, in two of our cases, integration across users was mandated from above (e.g., "Jointness"), and the process was far more challenging. Organizational consolidations among Federal government agencies are more commonly mandated (by the President, Congress, or high ranking officials), perhaps as a last resort when powerful stakeholders have different perspectives and conflicting goals. The strategy emphasizes major leaps in technologically-defined capabilities and hopes to seduce competing factions into cooperating and exchanging information (cf. Schein 1996). Especially when the downstream aspects are not stable, there is usually a struggle for control, with high-ranking government/military officials commandeering the technical programs for political advantage (Feldman & March 1981).

For systems engineering projects these political difficulties manifest as changing requirements, either the "requirements creep" of increasing scope or the "requirements churn" of back-and-forth change. In one of our cases the conflict among customers manifested as a contest between sponsors of different technologies for the same end users, which we characterize as a "Feud." In another of our cases the diverse range of sponsors all supported the same technology but each added their own requirements onto the only "train leaving the station," which they labeled a "Rice Bowl."

Centralization and Decentralization

It is tempting to resolve conflicts by empowering a central authority, either a single leader or a headquarters group, to make decisions and enforce them over competing stakeholders. Centralized authority should bring consistency, clarity, and lower long-term costs. Yet those doing the central planning often have only limited knowledge of the locally important issues, especially when designing for the future. A "practical drift" occurs over time which incorporates local task orientations in place of "overly burdensome" global rules, yielding a more stable local state of affairs (Snook 2000, p. 200). However, this "drift" also leads to a decoupling where local behavior and decisions become out of sync with the broader system, creating larger-scale inefficiencies and situations where significant problems can occur, such as the downing of the two Black Hawk helicopters by friendly fire (Snook,2000).

The debate over ideal organization forms (Eccles & Nohria 2002; Mintzberg 1970) has continued for some time, including in the IT world (Evaristo, Desouza, & Hollister 2005; King, 1983). In many companies such as Hewlett-Packard and Ford, governance structures have alternated between centralized and decentralized approaches, depending upon the preferences of top-level management, budgets, and the capabilities of the technology of the day. Organization theorists have suggested that alternating governance structures may even be preferable when there are both benefits and liabilities to a fixed choice between centralization and decentralization (Nickerson & Zenger 2002).

In one of our cases, for example, the approach to system development in a global technology environment was originally decentralized to allow for the exploration of innovative new technologies, rapid experiments with small failures, and a focus on unique local needs. Local technical successes could be scaled up to larger system-wide use as appropriate. This bottom-up organizing was coordinated and monitored by the intense involvement of a MITRE lead engineer to build trust and maintain open communication across the organization. During the long history of this program there have been periodic efforts to centralize planning for system architecture, technology development, and budgeting, followed by a slow drift toward a more local focus. Budgets have generally been locally controlled. However, the rapid evolution of technology capabilities led to difficulties in sharing information, software version control, and hardware selection. A recent effort to again gain some centralized control was captured in the comment, "He who has the gold, rules!" heard from several different sources in our case study research. This shift to a centralized budget approach and more centralized planning may address some challenges in the near term, but runs the risk of creating others.

Habits of Thought and Trustful Relations

Organizations are not just formal reporting relationships and divisions of labor, roles, and rules. Organizations are also interpretive systems, in that the formal structure is continually enacted according to the understandings of the participants whose actions constitute the formal structure and also modify it to suit changing circumstances and changing understandings (Orlikowski 2000; Weick 1979, 1995). Schein (1996) suggests that there are typically at least three subcultures in organizations: an operator culture or line organization that considers work to involve interconnected systems and cooperation among people; an engineering subculture that values technical, error-free solutions; and an executive subculture that focuses on the financial bottom line (see also Carroll 1998, who includes academic researchers as a fourth distinct subculture).

MITRE represents an engineering-focused organization with a high proportion of engineers as employees and as managers. Its customers have traditionally been on the technical side of their organizations, such as information technology. Hence, the habits of thought and practices of MITRE and its customers were well aligned with the technical capabilities that MITRE brought to the engagement. Trust was based on technical expertise, i.e., on capabilities necessary to solve the engineering problem or develop the new system architecture. Engineering management was primarily top-down project management, based around culturally-accepted bases of authority and shared goals of solving interesting problems to the mutual benefit of customers and MITRE. MITRE has generally been perceived by customers as objective, problem-focused, and technically-capable, and therefore trustworthy.

However, the new expansion into "enterprise systems engineering" brings with it new demands to work on problems that cut across disciplinary and organizational boundaries. MITRE engineers and project managers struggle to develop new habits of thought (cf.

Dougherty 1990; Schein 1996) and new practices that will allow them to act effectively in this new kind of situation. Technical problems now carry with them organizational, political, and cultural facets (Ancona, Kochen, Scully, Van Maanen & Westney 2005). As one interviewee said, “We try to be flexible… Listen, offer suggestions… Compromise, negotiation, alternatives… How do we go from nothing to a system of systems? Compromise is a big part of it.” [P3:5] Interoperability of technical systems also means agreement on principles of bringing groups together with different language, different priorities, different assumptions, etc. Trust is built on personal integrity and ability to translate across multiple groups, to present issues in a way that achieves consensus.

Contribution to Research on Systems Integration

In contrast to the small existing literature on systems integration, which assume a fixed customer base and relatively stable requirements (Davies 2003; Hobday, et al. 2005), several of our cases exhibit dynamic and conflicting customer groups. Thus, we suggest a stronger role of feedback loops involving customers, or directly between customers and manufacturing (via changing requirements) as an area for further research. On the systems engineering side, this suggests new skills in role taking, conflict management, and systems thinking (cf. Davidz 2006; Sterman 2000; Atwater, Kannan & Stephens 2008).

Although the problems experienced by engineers struggling with both the supply (technological integration) and demand (requirements) sides differ, the issues underlying both are closely tied to a pace of change so rapid that it prevents the kind of successful long-range planning traditionally central to the discipline of systems engineering. Traditional systems engineering approaches such as the waterfall method predicated on long development cycles and emphasizing formally structured requirements, specifications, and integration testing at the end of the project are no longer practical and new approaches such as spiral development are being tried.

There is also an accelerating, self-reinforcing feedback process between the rate of technological advances and the appetite of those in power for “more, faster, capabilities.” Key stakeholders such as large contractors, technology vendors, and government leaders may all have incentives to feed the innovation cycle. Engineering and political checks and balances are not always strongly in place. Engineering organizations such as MITRE lack power over these stakeholders, although they have "influence," and senior government officials may be unable (or uninterested) to keep their demands in line with what is technically feasible. Indeed, in the military environment, this is exacerbated by the easy transition of early military retirees into lucrative second careers in defense industries (*New York Times*, April 20, 2008). Our findings seem consistent with those of Bourgeois and Eisenhardt (1988) that in high velocity environments with rapid change in technology and demand, politics engendered through autocratic power centralization lead to diminished overall performance. And the difficulties are especially significant since under conditions of increasing uncertainty and more rapid change, the development of dynamic capabilities becomes of even more strategic importance than control over resources (Augier & Teece 2006).

Practical Implications

Focusing our investigation on the work activities of the systems engineers highlights the significance of systems integration in their project environments. It also affords a window onto larger, institutional changes as the programs MITRE supports shift their center of gravity (Davies 2003: 347) downstream from conceptual design of completely new technologies to systems integration of more commercial "off the shelf" (COTS) technologies. Many other contractors are experiencing similar changes from product to service, as in IBM's "Services Science." In one of our cases, the contractor's role "reduced significantly to a purely integration role. They have gone from major development and maintenance activities to just taking COTS and this government product and integrating and deploying." [P5:2]

MITRE was established in the late 1950s when the field of systems engineering and the industry structure were quite different. While commercial firms now find it expedient to actively "manage" upstream suppliers of component parts and assemblies, the government programs that MITRE supports are limited to "influencing" upstream suppliers. These programs are also legally constrained against providing the kind of operational and financial services that large, for-profit corporations involved in systems integration are providing as "integrated solutions."

As MITRE positions itself to provide enterprise systems engineering capabilities, it will likely need to go beyond asking its heavily involved systems engineers to add new skills to their technical expertise. At some point, MITRE may find it worthwhile to engage with its sponsoring government agencies in this effort, revisiting details of its FFRDC charters in order to consider how it can best catalyze change in the contractual and organizational arrangements of enterprise systems engineering project work. Similarly, there is increased need for thoughtful strategy about how MITRE can use its network of connections to influence underlying professional organizations to build trustful networks ahead of the need for specific technological change.

Limitations and Future Research

Of course, our research is based on only five case studies within a single and rather constrained (albeit significant) sector of government agencies. Further, each case study is based on a small number of interviews, in most cases with only MITRE personnel rather than a sampling of stakeholders, including the users of these systems, with their various viewpoints. Thus, we have a very particular, and possibly cloudy, window into the world of systems engineers and systems integrators. Certainly, our immediate research is continuing to deepen our case studies with additional interviews and to broaden our sample of MITRE engagements. Other researchers should complement this work with studies of other organizations.

However, what we have found is consistent with much of the existing literature and suggests directions for research on work and organizations. Indeed, we suggest that systems engineers are particularly well-positioned as 'canaries in the coal mine' to reveal elements of the emerging socio-technical realities of modern knowledge work. As Hobday, et al. (2005) assert, "Systems integration is growing and emerging as a key vehicle for organizing networks of production within and across the broader society." Focusing a research lens on the people who carry out that work on a daily basis should afford especially valuable results.

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