

MIT Open Access Articles

Dueling Stakeholders and Dual-Hatted Systems Engineers: Engineering Challenges, Capabilities, and Skills in Government Infrastructure Technology Projects

The MIT Faculty has made this article openly available. **Please share** how this access benefits you. Your story matters.

Citation: Brooks, JoAnn M., John S. Carroll, and Jon W. Beard. "Dueling Stakeholders and Dual-Hatted Systems Engineers: Engineering Challenges, Capabilities, and Skills in Government Infrastructure Technology Projects." IEEE Transactions on Engineering Management 58.3 (2011): 589–601.

As Published: <http://dx.doi.org/10.1109/tem.2010.2058858>

Publisher: Institute of Electrical and Electronics Engineers (IEEE)

Persistent URL: <http://hdl.handle.net/1721.1/74647>

Version: Author's final manuscript: final author's manuscript post peer review, without publisher's formatting or copy editing

Terms of use: Creative Commons Attribution-Noncommercial-Share Alike 3.0





MIT Sloan School of Management

MIT Sloan School Working Paper 4761-09
3/19/2010

Dueling Stakeholders and Dual-Hatted Systems Engineers: Engineering Challenges, Capabilities and Skills in Government Infrastructure Technology Projects

JoAnn M. Brooks, John S. Carroll, Jon W. Beard

© 2010 JoAnn M. Brooks, John S. Carroll, Jon W. Beard

All rights reserved. Short sections of text, not to exceed two paragraphs, may be quoted without explicit permission, provided that full credit including © notice is given to the source.

This paper also can be downloaded without charge from the
Social Science Research Network Electronic Paper Collection:
<http://ssrn.com/abstract=1481911>

Electronic copy available at: <http://ssrn.com/abstract=1481911>

**Dueling Stakeholders and Dual-Hatted Systems Engineers:
Engineering Challenges, Capabilities and Skills in
Government Infrastructure Technology Projects**

JoAnn M. Brooks, The MITRE Corporation

John S. Carroll, MIT Sloan School of Management
and Engineering Systems Division

Jon W. Beard, School of Management, George Mason University
and The MITRE Corporation

{ jbrooks@mitre.org; jcarroll@mit.edu; jbeard@mitre.org }

15 March 2010

Under review at:

IEEE Transactions on Engineering Management

Disclaimer: The views, opinions, and/or findings contained below are those of the authors and do not represent those of The MITRE Corporation except where designated.

MITRE Approved for Public Release, Distribution Unlimited
Case # 10-1032

Acknowledgements

We thank our research team – Betty Barrett, Michele Bishop, John Boiney, Theresa Fersch, Marc Halley, Leander Harding, Abigail Kirigin, George Rebovich, Vicki Sandiford, Katie Minardo Scott and Renee Stevens – as well as all research participants, and their managers who gave permission. Thanks are also extended to those who initiated and funded this collaborative research effort: Donna Rhodes and MIT's Engineering Systems Division, the Lean Advancement Initiative, MITRE senior managers, and the MITRE Technology/Innovation Program; and to Matt Burton who pointed us to infrastructure studies. Special thanks to those who provided feedback on case study drafts and earlier versions of the work, including participants at the EGOS 2008 Summer Colloquium and IWODE 2009, Steve Barley, Raghu Garud, Marion Michaud, Alan Moore, Donna Rhodes, Susan Scott, Diane Vaughan, Jeffrey Pinto, and two anonymous reviewers. Finally, Theresa Fersch and William Waters helped write the current version.

**Dueling Stakeholders and Dual-Hatted Systems Engineers:
Engineering Challenges, Capabilities and Skills in
Government Infrastructure Technology Projects**

ABSTRACT

Systems engineering projects that support government enterprises face substantial challenges due to demands from diverse stakeholders and rapidly-changing technologies. In this paper, we present findings from the analysis of five case studies of systems engineering projects for large government enterprises. We focus on what can be learned from systems engineers, their essential role, and their engineering practices. As they work to establish interoperability across pre-existing and new technologies while creating an evolving infrastructure, the engineers commonly face “agonistic” tensions between groups of stakeholders. Temporal pacing conflicts are especially prevalent, such as those between some stakeholder groups concerned with fast-paced streams of innovation and others concerned with current operations. In response, many engineers are following an evolutionary approach, developing new capabilities for incremental modularization and re/integration of technologies and associated practices across organizational (stakeholder) boundaries. Additionally, engineers are leveraging their professional role and developing new skills of influence to support these capabilities for addressing stakeholder tensions. We close by discussing implications of our findings for the management of infrastructure technology projects, for organizational design and engineering of government enterprises, and for the changing role of systems engineers.

INTRODUCTION

Systems engineering projects are becoming increasingly complex as government organizations use information technology to coordinate and consolidate the efforts of multiple agencies into *enterprises* that share information and provide services. Rather than developing a single stove-piped system for a hierarchically-organized customer, as in traditional systems engineering, these enterprise systems engineering projects confront multiple information and communication systems and technologies—many already in operational use—that must somehow be linked into a coherent *infrastructure* [15] for diverse and competing stakeholder communities. For example, the military services (Army, Navy, Air Force, etc.) are now being mandated to use interoperable communications and information technologies in an ongoing transition toward “net-centric operations;” similar pressures exist for national agencies including Health and Human Services, Homeland Security and Federal Aviation Administration. Further, in contrast to for-profit enterprises, government enterprises often lack both an overall hierarchical management chain and a bottom-line mechanism for evaluating success – a combination that renders their systems engineering projects all the more challenging.

This paper reports results from a research study on social and organizational aspects of large-scale systems engineering projects in five government enterprises. These case studies revealed that systems engineers are adapting both their capabilities for managing projects and their individual professional skill sets to meet the challenges inherent in this shift from systems to infrastructure. Our evidence suggests new implications for the management of infrastructure technology projects, for the organizational design and engineering of government enterprises, and for the changing role of systems engineers.

SYSTEMS ENGINEERING

Systems engineering began as a sub-discipline of engineering after World War II when the development of weapons systems, aerospace systems, and other commercial applications was expanding beyond the capabilities of independent engineering disciplines [22], [32], [35], [54]. By offering the label of “system,” the focus was placed on the entire *technical system* being engineered, such as a missile or airplane, rather than on the component pieces that were the responsibility of discipline-based sub-teams and subcontractors. Ferris [22] notes that a significant portion of the systems engineering approach was an emphasis on the planning and control of technical work.

Although systems engineering is still a relatively young and evolving field [60], its major activities have already coalesced around systems analysis, acquisition and supply, project management, system design (requirements and specifications) and integration, implementation or transition to use, and technical evaluation [35, p. 36], [41]. These traditional systems engineering methods for achieving interoperability and avoiding redundancies are predicated on long development cycles and emphasize formally structured requirements, specifications, and integration testing at the end of the project.

The concept of “system-of-systems engineering” (SoSE) [20], [36] emerged in the late 1980s to address a recognized need for an engineering approach that focused on the integration of multiple, complex systems [27].¹ Building on the systems engineering efforts for individual systems, SoSE emphasizes the “interaction” and “synergy” between independent systems toward overall system performance [34]. Yet, despite a number of efforts to codify the principles and

¹ Gorod and Sauser [27] provide a thorough and detailed history of the evolution of the SoSE field.

15 March 2010

practices of the discipline, SoSE has neither a coherent, widely accepted definition [52] nor agreement on whether or not the concept is even needed (cf. [10]).

Traditional systems engineering approaches and even SoSE approaches are still not sufficient to address some types of problems for large government enterprises [37], [47]. Hughes [32, p. 304] noted that systems engineering was continuing to evolve as more large-scale systems are developed in military and civilian applications, and is increasingly “a messily complex embracing of contradictions” with the projects being “socially constructed, not technologically and economically determined” (see also [60]). Further, Rouse [51] suggests that the emphasis for systems development has recently shifted from platforms to capabilities.

An emerging concept has come to be known as Enterprise Systems Engineering (ESE). Rhodes, Ross, and Nightingale [48] observe that the enterprise systems concept is “well accepted,” yet the research literature remains limited and “insufficient for many contemporary enterprises that are (or are evolving into) large-scale, global systems integrators or solution providers” (p.2). Enterprise systems often span multiple organizations, require a higher degree of integration, and must support varied and complex interactions among processes, technology, and people, without recourse to a hierarchical control authority [11]. However, in large enterprises with different systems and technologies evolving at different rates, component technologies must now be (continuously) integrated across different lifecycle stages so that traditional systems engineering approaches predicated on large sets of formally-structured requirements and long development cycles are no longer practical.

In this paper we present the results of an exploratory study of five large government-contracted enterprise systems engineering projects that vary in size, duration, complexity, and success. Our study examines the engineering challenges and the engineers’ adaptive responses with the intent of capturing emerging enterprise systems engineering knowledge and approaches

15 March 2010

that can be useful for understanding and improving the management of such engineering projects. Our primary research question was to understand and describe “enterprise systems engineering” – how it was different from traditional systems engineering. A secondary question was how experienced systems engineers were addressing these differences in their work.

METHODS

Because theory on our research questions was nascent and there was little a priori specification of constructs, empirical field research was needed to develop theory, with special attention to issues of validity [60]. We used a qualitative research approach: comparative case studies for theory development [18], [62]. Our research team included three senior engineer practitioners and several social scientists.² This diversity of researchers’ backgrounds helped to limit bias [19, p. 28] during data collection and analysis, and ensured that we had adequate expertise to understand both technical and organizational contingencies relevant to systems engineering work.

Case Selection

We had access to cases contracted between government enterprises and the MITRE Corporation, a not-for-profit organization that administers several Federally-Funded Research and Development Centers (FFRDCs) involved in the technical design of large information and communication systems for government enterprises. FFRDCs are not-for-profit organizations outside of the US government that conduct research and/or do systems engineering work for federal government agencies; comparable organizations exist in other nations as well.

We selected cases according to theoretical sampling to support replication logic [18], [62]. This enabled us to use each case as a separate field experiment in evaluating inferences

² The number of social science members on the team fluctuated between three and five over the three years of the project, Fall 2005 – Summer 2008.

15 March 2010

drawn from the others. We selected five cases all of which were large in size (tens of thousands or hundreds of thousands of users) and that spanned across a range of customer groups and levels of success. The cases also varied in length of project, maturity of technologies, and national setting. Case details are provided in Table 1.

<< insert Table 1 about here >>

Data Collection

We gathered data from multiple sources – interviews, observation, and documentary materials – to enable triangulation and increase construct validity. Our primary source of data was interviews conducted by a team of researchers with different backgrounds which also supported confidence in our conclusions. Interviews were typically held at the site where the engineering work was ongoing, which permitted observation. Researchers also obtained other background information, reviewing newspaper articles, web sites, and archived project materials, and attended a project conference for one of the cases.

To enable effective data collection on topics with highly technical content, the engineers on the research team assumed key roles in designing the interview protocol and conducting the interviews. The engineer-researchers were first trained by the social scientists on appropriate methods for conducting objective and thorough interviews. With the close involvement of their social science colleagues, the engineer-practitioner researchers composed a series of questions for a semi-structured interview protocol (see Appendix) designed to be similar to the types of conversations that engineers typically have with each other, in order to encourage candid sharing.

Senior managers overseeing each project provided the names of project leads who then identified qualified potential interviewees for each case study. All but two of the interviews were led by an engineer-researcher, with at least two researchers with social science backgrounds

15 March 2010

taking notes and interjecting clarifying questions as necessary. Interviews lasted between sixty and ninety minutes. Social science researchers typed up their notes shortly after the interviews and the engineer-researchers helped interpret acronyms and other engineering terminology.

Between three and six interviews were carried out for each case during the 2006-2007 timeframe; we refer to these as “Tier 1” interviews. Some additional (“Tier 2”) interviews were conducted in 2008, using questions developed after the preliminary analysis of Tier 1 data. Altogether, a total of 30 interviews with 27 individuals were conducted across the five cases.³ Additionally, one social science researcher sat in on three interviews with engineers from a second government agency in the Beta case, courtesy of an independent research project conducted by the Defense Acquisition University; this data was especially useful in balancing different perspectives across agencies in that case.

Analysis Process

We took precautions to counteract potential investigator bias during the analysis phase. The data collection and case-writing phases overlapped, during which time the team held weekly meetings to compare data, discuss cases, iteratively refine constructs and develop emerging themes, incorporating the views of both social science and engineer members of the research team. Each case was separately analyzed and written prior to the cross-case analysis. In addition to triangulating across multiple sources of data, multiple people with different backgrounds were involved in the writing and reviewing of each case study.

To ensure basic consistency of format across the case studies, the team created a common case outline. One or two authors then prepared a detailed case write-up for each individual project, first reading through all transcribed notes from the interviews on that case, and then

³ Of these, one of the Tier 1 interviews involved two interviewees rather than just one; and four of the Tier 2 interviews were with people we had previously interviewed in Tier 1.

15 March 2010

performing ad hoc coding to identify key themes particular to each case. Each case study was written as a detailed history, including a timeline of critical events, organizational charts, program accomplishments, challenges faced, engineering practices, lessons learned, and suggestions for further research. Each case was then iteratively reviewed and revised – first by other social science members of the team, then by a researcher-engineer, then by the interviewees from the project, and finally by the corporate project manager. When engineers differed on their interpretations of case details, we discussed the matters and found ways to write the cases that they could then agree upon. Higher-level managers had a broader view of the project contexts and were able to recommend additional interviews to fill in gaps in the data, as well as how to redact the data to eliminate unnecessary risks to the projects or to individuals. This combination of multiple reviews from different perspectives strengthened the validity of each individual case write-up.

The team began preliminary cross-case analysis as individual case studies were being finalized. Tabular matrices [42] were developed to identify themes across the cases, which were then presented to interviewees for review during two workshops; these were also reviewed by senior managers. After all individual cases had been completed and accepted by interviewees and project managers, the principal investigator initiated the formal cross-case analysis, reviewing all of the original interview notes, the five case studies and memos on the high-level themes, before completing a second round of coding across the entire five case data set. These results were reviewed by social science team members, engineers, and managers. Relevant literature was iteratively compared with the emerging results to further refine our findings and was incorporated in the written products.

FINDINGS

Challenges

Our data revealed that the engineers experienced major difficulties related to instability in the environment and systems requirements – instability which often prevented the traditional systems engineering processes from reaching completion. One Delta engineer described the challenge as “many moving parts, [which] constantly move.” A Beta engineer reported that the complexity of the enterprise organization “broke a significant number of the traditional systems engineering practices that we depend on.”

Much of the instability emerged from several distinct kinds of conflict or tension among stakeholders. Two of these categories of tension are consistent with those found in the development of computer infrastructures [16]: *interest and exclusion* and *ownership/investment models*. However, our results extend their approach in two ways: First, our data suggest that there is a significant difference in the success of the project depending upon the organizational design of the enterprise (see Table 2); and second, we identified a new category of agonistic tensions – *pacing* of development (see Table 3). We elaborate on these tensions below after a brief summary of the relevant work on infrastructure.

Infrastructure Evolution and Agonistic Tensions

The historian of science and technology Paul Edwards and his associates draw a sharp distinction between technical systems and infrastructures in computer system development. They assert: “In general, ...*infrastructures are not systems*. Instead, they are networks or webs that enable locally controlled and maintained systems to interoperate more or less seamlessly” [16, p. 12; emphasis in original]. According to this view, infrastructures develop through stages, beginning with the *system building* stage, in which “visionary” designers exercise considerable control. However, in the *consolidation* phase, separate systems and/or networks are linked

15 March 2010

together – first in smaller area networks and then more globally. This is accomplished either by one system taking over, or more commonly through the use of *gateways*, which are “technologies and standards” that “allow dissimilar systems to be linked” [16, pp. i, 8, 10].

One of the most notable characteristics of this infrastructure consolidation phase is the surfacing of political conflicts, or “agonistic” tensions:

in their moments of emergence, infrastructures can be a site of intense conflict
... Infrastructures in the making ... are ... *agonistic* phenomena: imagined, produced,
refined, and occasionally reassessed in a stratified and deeply conflictual field [16, p 24].

Drawing from work by Star & Ruhleder [57] on the importance of social practices relative to infrastructure development, Edwards *et al.* [16] stress that technological consolidation is generally easier to manage than are the attendant changes in relations between social and organizational units. This is because developing infrastructure entails redistributing resources and opportunities, therefore engaging a “deep politics of design” in which “people and groups fight over, around, and through the systems and networks that govern their lives” [17, p. 372].⁴ Our cases were replete with data for two of these types of tensions, which are described next, and are summarized in Table 2.

Tensions around Interest and Exclusion

Every infrastructure development effort has perceived winners and losers as the distribution of opportunities and influence change [16, p. 24]. These tensions were so common that one Delta engineer off-handedly referred to “food fights” over requirements. Such tensions also commonly surfaced in struggles around practicalities of designing technology gateways to bridge across different systems and networks, as experienced by the Gamma engineers:

⁴ Re-distribution effects of government information and communication infrastructure projects appear to be stronger and more immediate than those of physical infrastructure projects such as roads and bridges, public utilities and airports (cf. special issue of *California Management Review* on “Infrastructure Meets Business,” Winter 2009, 51(2)).

15 March 2010

“Originally we were struggling with – ‘Can we develop in time and within budget?’ Now we’re trying to fill all the needs and that answer will be ‘No.’”

Tensions around Ownership / Investment

Similarly, the engineers were well-aware that funding mechanisms, policy options, and other external constraints were significant sources of tension for their engineering projects. A Gamma engineer stated: “When outsiders dictate which [gateway technology], you lose control and there’s higher risk.” Tensions with external stakeholders also commonly surfaced around funding and budgetary arrangements: “Congressional districts are among the stakeholders— How do you deal with the congressional politics?” (Epsilon) “The ... industry controls a large portion of ... jobs in congressional districts.” (Gamma)

Agonistic Tensions and Project Success / Failure

In looking across the five cases we found that the projects that the engineers generally considered more successful exhibited less disruption from interest/exclusion tensions. The Alpha and Delta projects were identified as relatively successful — they were also the only two cases out of the five in which member organizations had joined the government enterprise voluntarily. For example, an Alpha interviewee indicated: “Some people didn’t want to be an Alpha node because they had other things to use their money for... Others were jumping on the bandwagon... ‘We’re Alpha all the way.’” Alpha and Delta projects were developed within well-established government enterprises which were relatively stable and had agreed-upon governance mechanisms in place to enforce member compliance. In contrast, each of the other three projects labored under a government mandate to link together systems and technologies as a means to consolidate a new government enterprise to be comprised of organizational units that traditionally competed with each other for funding and political recognition. In these cases project management seemed to try to satisfy everyone, ending up over-committed and under-

15 March 2010

resourced, with the result that the projects experienced more volatile and disruptive interest/exclusion tensions and the mandate became recognized as infeasible. One interviewee reported that the Gamma effort “affected just about every program in the [service branch] – caused a lot of churn for systems that should never have had it ... one of the most laughed at mandates.... It wasn’t clear that you could do all that with software or get the crypto to work – we laughed and we cried.” Additional data supporting these findings are summarized in Table 2.

<< insert Table 2 about here >>

Some interviewees hypothesized that the mandates for such ambitious consolidation efforts were learning “experiments” intended to find where the limits were. Yet the fact that these failures were so enormously costly casts doubt upon such wisdom, and foreshadows our next result.

Tensions around Pacing

We were particularly struck by a consistent set of tensions around differences in stakeholders’ orientations to the pace at which the evolutionary *process* of infrastructure development itself should proceed (see examples in Table 3). Clashes between organizations responsible for exploiting fast-paced streams of innovation and those concerned with slower-paced testing and operational fielding processes occurred in all of our cases (cf. [1]). The former were long-range planning or R&D organizations (often bearing names that included “lab” or “experimentation” in their title). The latter were government organizations either directly engaged in current operations or responsible for the “acquisition” of technologies to meet the needs of users already working in the field (users dependent upon situated combinations of legacy and innovative technologies).

There is an inherent structural tension between these types of organizations. The expectations for improvisation and discontinuous change that are common within cultures of innovation contrast with the institutional arrangements for “acquisition,” i.e., the contractual,

15 March 2010

legal, and regulatory arrangements for how new technological systems are to be funded, built, and fielded, which are rigorous and proceed cautiously in order to minimize risks (cf. [40]). In our cases, senior officials concerned with “transformation” of military forces or “next generation” civil technologies advocated discontinuous change, whereas senior officials primarily concerned with ongoing operations and end-users already out in the field displayed little tolerance for any change that was more than incremental. One Beta engineer described these inter-organizational tensions explicitly:

there was conflict between the acquisition side, [which was] relying on historical understanding of what it takes to field a product in a safe and suitable way, and a [rapid prototyping / agile] group who was trying to foster a leaner and new approach. Distrust, mistrust, second-guessing, not best of relationship. ... ‘Us’ vs. ‘Them.’

Similarly, a Gamma manager offered an eloquent description via email: “There are loosely two camps. One camp ... tend to emphasi[ze] leap-ahead capability. Their focus is on the [technology] to be fielded [ten years out]. The other camp... tend to emphasize more rapid fielding across the broader force (e.g., lower-cost, good-enough capabilities).”

These pacing tensions were exacerbated by rapid leadership turnover. Large infrastructure technology projects which take many years to complete were usually initiated by individuals who occupied their positions for only two to three years before moving on to other jobs due to political appointments or military rotations. Thus, there was rarely a single individual in charge of the entire project for long enough to effectively mediate differences among the stakeholders or dictate final decisions. One Gamma engineer described such a situation: “The program was already going, processes already in place. Then the new [program executive officer] was trying to put his new [plan] in place. Trying new architecture, requirements, specs. People were already building things. ...Other things start clean. So, we’re a little broken in my mind.” In response, mid- and lower-level personnel in both the civil service and military commands, who were long-term (if not lifetime) employees, were tempted to simply

15 March 2010

wait for the leader-initiated change efforts to “blow over” as the leaders left, a tactic referred to as “slow rolling.” One Alpha interviewee made the point explicitly: “The culture is changing, but only because I think [the top two leaders] have stayed there long enough if people don’t see the value, they will slow roll you.” Pacing tensions manifested in many different ways as summarized in Table 3, although “requirements creep” and “requirements churn” seemed especially ubiquitous throughout the cases.

<< insert Table 3 about here >>

Developing Capabilities: Changing Engineering Management Practices

Some of our interviewees indicated that they are responding to the challenges of the agonistic tensions in their projects by following an evolutionary approach. Denning, Gunderson & Hayes-Roth [13] posit that an evolutionary approach that involves “continual adaptation to the environment” through “successive releases” of new technology and/ or survival of the fittest technology is necessary to reverse the increasing rate of failure in large system projects. Our findings show that these adaptive engineering management practices can be understood more specifically as capabilities of incremental modularization and reintegration across organizational boundaries. Systems engineers are modularizing large systems and networks into smallish “chunks” and then working to recombine them in different ways at later times. Data summarizing these findings are summarized in Table 4.

<< insert Table 4 about here. >>

Modularizing Technologies

To support separability and recombining of components, engineers were developing capabilities for modularizing technologies. As an Alpha engineer explained, “For information systems, take on acquisitions that you can do within a year – completed within lifecycle – longevity of requirement. You basically evolve systems, pick off bite-size increments. Try

15 March 2010

things and take risks, and if it doesn't work, throw it out and start again." As the engineer noted, smaller chunks have shorter project timelines, which helps to avoid requirements creep and adjust to changing constraints and policies. Therefore, systems engineers are more willing to cancel or change projects and shorten completion times. For example, Delta projects were operating on "task order" contracts that supported multiple exit points where engineers could decide whether to renew the contract, thus allowing them to adapt to changes more readily.

Data revealed reliance on prototypes and the use of less expensive and readily-available COTS products that also helped with shortening the time-frame from requirements through development to fielding. "Prototyping is key ... it is used to better capture user requirements and to validate as early as possible man-machine interface, etc." (Delta). Engineers pushed prototypes and/or COTS tools out into the field to circumvent the slow formal acquisition process, sometimes simply re-categorizing them to move them into the hands of operational users in a timely fashion: "Many [user groups]...are pursuing alternative interim solutions ... they use the term 'interim' to get it approved." (Gamma). Such smaller chunks of technology facilitated the reconciliation of interoperability constraints and eased the approval and acceptance process, in addition to the technology transfer phase that precedes consolidation during the infrastructure evolution process [16].

Integrating Across Actors in Conflictual Fields

Once technologies and programs had been modularized, a different set of challenges, also illustrated in Table 4, emerged as the modules were integrated back into new arrangements. For example, the Alpha case involved consolidation of over 100 different types of databases into a small handful of large database systems. Such technical challenges were perennially compounded by agonistic tensions and disagreements over how re-combinations should be accomplished.

Our data indicated that engineers developed a range of capabilities to meet these challenges. One basic integration practice involved redrawing boundaries around collections of legacy and engineering programs to forge new program identities. For example, after having already been in existence for 4-5 years, the Delta project was being renamed to reflect a change of scope from an exclusive focus on military capabilities to one accommodating interoperability with other governmental elements: “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.” A new name would support new conceptualizations and practices around a broader scope.

More generally, engineering management practices for integration rely on agreements represented in schedules and documents and other boundary objects [8], [56]. A sample of these are included in Table 4 (in bold). Higher-level (i.e., “organizational”) interdependencies were commonly coordinated through the use of documents. For example, a Concept of Operations (“CONOPS”) document spells out the processes in which a required technology is expected to be used, and a Performance Requirements Document (“PRD”) is a written specification of what the technology should be able to do once it is built / delivered. At the lower levels, where many more technical details must be tracked (such as managing changing requirements and risks), interdependencies were usually coordinated with software tools such as spreadsheets or databases; the Dynamic Object-Oriented Requirements System (DOORS) was one such tool.

To yield effective integration, changes in boundaries, names, and documentary objects must be linked with complementary adjustments in stakeholder practices. Our data indicate that the most common approach to harmonizing stakeholder practices involved instituting a recurring series of meetings attended by a consistent set of representatives from groups affected by the relevant technological interdependencies. These meetings occurred at multiple levels throughout the enterprise; depending upon the program and level of representative members, they were

15 March 2010

termed “boards,” “integrated project teams” (IPTs), “working groups,” and so forth as highlighted in the Integration Capabilities column of Table 4. Representatives normally included some subset of the stakeholder and subject-matter expert groups specified in the Prince 2 methodology (i.e., line management, project management, resource manager, operational customer, support organization, and transformation organization) [46].

Within these recurring meetings, agonistic tensions of inclusion/exclusion, ownership/investment, and temporal pacing would emerge and would normally be addressed pragmatically [9] by collective decisions about how to manage interdependencies. Participating representatives would then carry the decisions back to their separate organizational units, which would then modify their practices accordingly. The agreements and decisions represented in boundary objects could thus be likened to “knots in the web of infrastructure technologies and concurrent socio-institutional provisions” [16, p. 36], tying together the different participants’ orientations and technological trajectories.

Our data also revealed several enterprise-level capabilities for integrating changes in technologies and practices. In the Delta enterprise, engineers relied upon a “Capability Package” mechanism. This approach united financial, technical, and organizational dimensions of the enterprise in a single formal process for initiating funding and facilitating budget planning and the design of technical requirements and architecture. It was initiated at the highest level of enterprise management and progressed through consensual agreements to deeper levels of detail. Although a “slow and cumbersome” process, it generally resulted in consensual agreements about how to move forward with engineering decisions.

Another enterprise-level means for integrating a multitude of components and stakeholders was the “spiral development” model used in Beta, which emphasized iterative cycles of integration and operational testing as major linkages between technology development

15 March 2010

and fielding. This involved provisionally accepting large numbers of new candidate technologies (termed “initiatives”), testing them against a baseline system in orchestrated field “experiments” that involved up to hundreds of participants, and then moving forward with those technologies deemed successful. It was usually carried out incrementally and iteratively [45] as a process extending over multiple years with new technologies diffusing out into field use via managed increments and in accordance with CONOPS developed through the exercises.

Finally, if all other integration efforts failed, a last-resort strategy more in keeping with both military and traditional systems engineering approaches was to consolidate budgetary and managerial control within a single “executive office” responsible for the systems engineering effort. Such efforts to rein in divergent stakeholders were attempted in various forms across all five cases; however, tensions continued to emerge between the formal hierarchies, operational users in the field, and newer innovative improvisations leading to eventual fragmentation [30].

Role of Systems Engineering Professionals and Skills for Influence

In explaining how they developed and utilized modularization and integration capabilities, interviewees offered many observations and insights about aspects of their role that were challenging, surprising, and often different from their training and preparation. We identified two major themes from the interviews – ambidextrous roles and influence skills – as illustrated by the quotations in Table 5.

<< insert Table 5 about here >>

Systems Engineers Play Ambidextrous Roles

As mentioned above, the systems engineers we interviewed were employees of an FFRDC in the US or a comparable international organization; each such organization is responsible for a large umbrella contract with one or more specific government agencies. The systems engineers work on separate, individual programs within that government agency or

15 March 2010

agencies. Whereas the immediate customer (government agency program office) is responsible for performance of a specific technology program, the umbrella contract emphasizes both the work for the immediate customer and higher-level concerns regarding enterprise capabilities, including interoperability. Therefore, the systems engineers are ultimately accountable both to managers within the program office *and* indirectly – through the management chain within their FFRDC (or equivalent international) organization – to higher-level executives at the project’s sponsoring government agency.

As a result, the systems engineers juggle competing evaluative criteria stemming from their often physical location within the customer organization (cf. [35], [54]), and their career progression within the contractor organization and their collaborative projects.⁵ As illustrated in Table 5, some senior systems engineers talk about being “dual-hatted” which means they have one job title for their employer and another for their customer. “I am dual-hatted, I run the [FFRDC] project that supports the [government program executive office] and I also, from the government perspective, run the systems engineering organization for [that same government program executive office].” Others simply juggle responsibilities anyway.

This balancing of accountability to different stakeholders is especially important in enterprise systems engineering because, as noted previously, competing stakeholders and individual programs often have few incentives to cooperate with each other. The systems engineering organization thus affords a potential “back-channel” for enterprise communication and management concerning technical decision-making during infrastructure development. Systems engineers working for an FFRDC therefore have a significant resource in their access to information and people, and to each other: “These [FFRDC systems engineers] at commands have a back channel, so they started hooking [government agency] people up especially as doing

⁵ Star & Ruhleder [57] emphasize the importance of local/global difference in infrastructure, although their emphasis is more on end users than developers.

15 March 2010

technical design work... in trying to get command issues teed up ahead of time.” (Alpha) Or as a senior Epsilon engineer noted, “Different [stakeholder] groups ... don’t align... They don’t align yet, let me put it that way. If we’re successful, they’ll have to align.”

Systems Engineers Cultivate Influence Rather Than Power

Although a few senior systems engineers are formally dual-hatted and occupy positions of legitimate authority within the client organization,⁶ most systems engineers assume individual contributor roles (presence on teams, liaison roles, etc.) within the client organization. Their influence therefore depends on their reputation and relationships rather than any formal authority. An interviewee referred to the systems engineering unit of the Epsilon program as an “office of influence. No budget, do not implement... no authority, but a lot of influence.”

Sources of influence range from the more technical to the more interpersonal. On the more technical side, the systems engineers have generally been perceived by customers as objective, problem-focused, and technically-capable, and therefore trustworthy. As an Epsilon interviewee said, “we do good analysis, we have good reputations so they come to us.”

Engineers have also generated influence through providing demos and “technical guidance.”

But, increasingly, technical expertise is insufficient as a source of influence. “When I [first started], we did technical problem solving; now it’s cultural problem solving.” (Epsilon) “Success of projects is about people. If you don’t know [the right] people, you can work for a long time and not succeed.” (Delta) As a result, systems engineers find themselves exercising influence and even leadership from a strategic position at the nexus of information and relationships, but without any explicit training or skill base. “I was put here [by my General Manager] for a reason and nobody is giving me a recipe. You have to do this by instinct, figure

⁶ These senior project leaders were overrepresented in our interviews.

15 March 2010

out a path to get what you want.” (Epsilon) “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.” (Beta)

These observations about the “people skills” needed in senior systems engineering roles should not be entirely surprising. Decades ago, Hall [29] identified five traits of the ideal systems engineer, two of which were “facility in human relations” and “a gift for expression” (the others were technical). More recently, NASA identified five themes among characteristics and behaviors frequently observed in highly regarded systems engineers [61]: Leadership, Attitudes & Attributes, Communication, Problem Solving & Systems Thinking, and Technical Acumen. Under Leadership, for example, there are ten competencies such as “Possesses Influencing Skills” and under each competency there are descriptions of observable behaviors, including “Understands the political forces that affect the project,” “Influences actions of personnel not under their direct management,” and “Builds a base of contacts, information sources, knowledge, and expertise.” Overlapping behaviors and competencies reappear in other themes, such as “Gains respect, credibility, and trust” (in Attitudes & Attributes) and “Facilitates an environment of open and honest communication” (in Communication).

Thus the engineers have been developing a constellation of capabilities and skills to meet the challenges associated with the endless stream of changes in their development environment.

DISCUSSION

The intent of our research project was to capture the emerging knowledge among systems engineers about their enterprise level challenges. Our results contribute in several areas: 1) the management of infrastructure technology projects, 2) the organizational design and engineering of government enterprises, and 3) the changing role of systems engineering.

Management of Infrastructure Technology Projects

Although organizational conflicts around the development of information systems have been well-noted in the literatures for information systems (e.g., [38], [39], [43]), systems engineering (e.g., [22], [32]), and management (e.g., [21], [44]), we found special value in work by Edwards *et al.* [16] for developing understanding of enterprise-scale systems engineering. Their explanation of the consolidation of traditional systems into infrastructures and the attendant agonistic tensions shed light on the challenges that the engineers had described. More recently, Edwards *et al.* [17] continue to develop an agenda for understanding and addressing the agonistic tensions in infrastructure development.

Our findings about engineering capabilities and skills extend Edwards and colleagues' ideas and their case studies toward even larger and more complex infrastructure efforts. Looking at the evolving infrastructures of these large government enterprises, we find that capabilities of modularization and integration, coupled with skills for influence, are critical for engineering within these agonistic environments. These findings add specificity to the general notions of loosely managed cooperation among developers and use of an evolutionary approach in IT development [13]. And in contrast to previous research concentrating on specific types of modularity (e.g., [53]), our work highlights a broad range of modularization practices, such as using prototypes and shorter contracts, as capabilities that systems engineers are developing for achieving modularization. Similarly with regard to integration, our finding that engineers are developing new skills and capabilities for managing interdependencies across organizational units and practices adds to and complements existing work on management techniques for achieving technological interoperability. Additionally, our identification of pacing tensions adds another dimension to Edwards *et al.*'s [16] categorization of agonistic tensions in infrastructure.

Organizational Design and Engineering of Government Enterprises

While there is a large body of literature that recognizes complementarities between organizational design and the design of information systems and technologies (e.g., [3], [5], [23], [39]), our results advise caution in assuming that these ideas are directly transferrable to government enterprises and infrastructures. Whereas organizational design may be managed through strategic (top-down) design and supported with enterprise resource planning systems, government efforts to mandate enterprise consolidation are at much greater risk of degenerating into destructive fields of agonistic conflict if they suffer from leadership turnover and lack of agreement over assessment criteria [14], and when effective governance is not already in place.

Our research directs attention in particular to the *pacing* tensions that arise during infrastructure consolidation – a form of conflict alarming to observe in an institutional field of public government enterprises. We found that as each stakeholder organization struggled to entrain to multiple pacers within its enterprise environment, major oppositional tensions emerged between reliance on structure embedded in traditional hierarchical cultures, and celebration of creative destruction in innovation cultures. This enterprise-scale result was sometimes more like a war over which organization would submit to the other’s pace rather than a benign “dance of entrainment” [2] or inevitably “linked elements of a larger formulation” [49]. The failures of Beta and Gamma in particular were extremely costly – temporally, financially and reputationally, not to mention morale-wise – when government mandates attempted to force competing organizations into a consolidated enterprise using emerging technologies as the “tip of the spear.”⁷ We suspect that such tensions may be stretching the limits of systems engineering capabilities to the breaking point, especially in light of the path dependence that “locks in” effects of choices and that can lead to dominance of inferior technologies over potentially

⁷ Especially as was previously done through techniques of business process re-engineering (BPR).

15 March 2010

superior solutions [16, p. 17], [59]). Therefore, initiators and higher-level managers of government infrastructure efforts must become attuned to potential mismatches in temporal cycles across the intended enterprise.

A more optimistic finding is that systems engineers' newly-developing capabilities can facilitate the continual process of organizing and re-organizing organizational units and practices within these turbulent environments of agonistic tensions and technological innovation. These engineering capabilities provide an engineering-oriented complement to the growing body of organizationally-oriented theories of task articulation and rearrangement of work practices, routines and processes for accommodating new technologies (e.g., [6], [24], [25], [26], [55]); together they point to new ways to resolve local–global tensions in infrastructure development [57].

The Changing Role of Systems Engineers

Systems engineers have traditionally had a professional responsibility and a unique role in terms of "systems thinking," i.e., being big picture “visionary” designers [16] who manage technical constraints within relatively stable environments. But in unstable multi-stakeholder infrastructure projects they must find a delicate balance between what will work technically and what will work politically, along with what will satisfy the basic intent of the engineering task.

Because systems engineers are not often tied to one specific funder, but are assumed to be available to whichever funders come out on top, they have some clout in helping (or hindering) competition between funders. Systems engineers thus find themselves in a key leverage position for determining each next step in emergent organizing processes: they are technically savvy and familiar with many stakeholders while their training predisposes them to avoid taking political sides. Combining technical knowledge and familiarity with the role of honest broker across multiple stakeholders thus renders systems engineers in a position to be a “back channel” for

15 March 2010

integrating across stakeholders in ways somewhat analogous to labor negotiators and international diplomats.

The necessary skills for exercising influence and getting things done through other people, particularly in a multi-stakeholder environment, have rarely been taught but are now entering the systems engineering curriculum. These skills include listening, delivering persuasive arguments, role-taking, relationship building through competence and integrity, and negotiating (including compromising and finding win-win solutions) [4], [12], [47], [58], [61]. Commenting on the need to combine academic education with real world experience, Ring and Madni [50, p. 975] suggest that “no academic institution can provide a sufficient learning environment for developing SE practitioners.”

In the meantime, systems engineers working on government infrastructure projects are already developing a somewhat different skill set than the linear technical analysis of traditional systems engineering. Prototypical behaviors that were invented by senior systems engineers in our cases included the recurring meetings of representatives from affected organizations, and the “backchannel” networking among MITRE engineers that span organizational boundaries among stakeholders. These afford manifold practical implications for a more “holistic engineering education” [28], as well as for review and evaluation of their accomplishments. Beyond the individual competencies of systems engineers, there are implications for the overall management of systems engineering programs and thoughtful strategy about how systems engineering organizations can use their connections to build trustful networks ahead of the need for specific technological change.

Limitations and Future Research

Our research is based on five case studies within a highly constrained set of government sectors, and most of the projects are still ongoing. Further, each case study is based on a small

15 March 2010

number of interviews, in most cases with only MITRE personnel rather than a broad sampling of stakeholders. However, our results are consistent with a growing literature on the limitations of traditional systems engineering and the need for advanced systems engineering capabilities.

Research is needed to accumulate a broader set of examples of large, multi-stakeholder government infrastructure projects, including longitudinal studies of practices and their degree of success. We would especially like to see more research on spiral development (cf. [7]) which seems to offer promise for managing infrastructure development tensions. Research contrasting non-government cases would also be very interesting.

CONCLUSION

In this paper we have leveraged practitioner perspectives to identify challenges facing systems engineers working on government infrastructure technology projects and the capabilities and skills they are developing in response to those challenges. We found that agonistic tensions surface during the infrastructure consolidation phase, especially when stakeholder relations are not already well-established and, at least in our government cases, particularly with regard to the pacing of enterprise change and infrastructure development. There is some preliminary evidence that the success of these projects is related to the way agonistic tensions are managed. In their adaptive response to the difficult experience of these tensions, systems engineers are developing capabilities of modularization and integration to facilitate more rapid and flexible organizing and new relational skills, especially with regard to influence and functioning as a trusted and well-connected neutral third party. Whether these adaptations will be adequate to meet the challenges remains unclear at this time.

We see several possible paths forward, all of which support the observation that “reliable systems for surfacing and dealing with [infrastructure] tensions need to be put in place” [33].

First, while systems engineers are not at the executive level, there may be advantages to raising

15 March 2010

their positional authority, at least of a chief engineer or project manager, and highlighting the importance of the role of “honest broker” to moderate agonistic tensions. Second, these challenges are not the sole responsibility of systems engineers; there should be changes in complementary roles, e.g., managers of systems engineers, project managers, stakeholder leaders. Finally, infrastructure development and sustainability, especially in contexts of rapid leadership turnover and lack of consensual evaluative criteria, requires special attention to the tensions between innovation and integration. Hobday, Davies, and Prencipe [31] note that systems integration is an organizing crux for networks of large-scale economic organization. Like canaries in a coal mine, the experience of enterprise systems engineers may be forewarning of an uninhabitable environment. What would be our best intelligent response?

REFERENCES

- [1] Ancona, D. and C.-L. Chong (1996). "Entrainment: Pace, cycle, and rhythm in organizational behavior." Research in Organizational Behavior **18**: 251-284.
- [2] Ancona, D. and M. J. Waller (2007). "The dance of entrainment: Temporally navigating across multiple pacers." Research in the Sociology of Work **17**: 116-146.
- [3] Avital, M., R. J. Boland, and D. L. Cooperrider (Eds.) (2008). Designing Information and Organizations with a Positive Lens, Advances in Appreciative Inquiry Series, Volume 2, Elsevier Science, Oxford.
- [4] Atwater, J. B., V. R. Kannan and A. A. Stephens (2008). "Cultivating systemic thinking in the next generation of business leaders." Academy of Management Learning & Education **7**(1): 9-25.
- [5] Bailey, D. E., P. M. Leonardi, and J. Chong (forthcoming). "Minding the gaps: Understanding technology interdependence and coordination in knowledge work," Organization Science.
- [6] Barley, S. R. (1990). "The alignment of technology and structure through roles and networks." Administrative Science Quarterly **5**: 61-103.
- [7] Boehm, B. and W. J. Hansen (2001). "Best Practices: The spiral model as a tool for evolutionary acquisition." CrossTalk: The Journal of Defense Software Engineering, May.
- [8] Carlile, P. R. (2002). "A pragmatic view of knowledge and boundaries: Boundary objects in new product development." Organization Science **13**(4): 442-455.
- [9] Carlile, P. R. (2004). "Transferring, translating and transforming: An integrative framework for managing knowledge across boundaries." Organization Science, **15**: 555-568.

15 March 2010

- [10] Clark, J.O. (2009). "System of systems engineering and family of systems engineering from a standards, V-model, and dual-V model perspective."
http://www.incose.org/hra/past_events/IEEE2009_SoSEandFoSE_JOC_090223.pdf.
Accessed 27 February 2010.
- [11] Crider, K.A. and J. K. DeRosa (2007). "Findings of case studies in enterprise systems engineering." 1st Annual Systems Conference, April 9-13: 1-6.
- [12] Davidz, H. (2006). "Enabling systems thinking to accelerate the development of senior systems engineers." Engineering Systems Division. Cambridge, MA, Massachusetts Institute of Technology. **PhD**.
- [13] Denning, P. J., C. Gunderson, and R. Hayes-Roth (2008). "The profession of IT: Evolutionary system development." Communications of the ACM **51**(12): 29-31.
- [14] Dunbar, R. L. M. and R. Garud (2009). "Distributed knowledge processes and indeterminate meaning: The case of the Columbia shuttle flight." Organization Science, **30**(4): 397-421.
- [15] Edwards, P. N. (1998). "Y2K: Millennial reflections on computers as infrastructure." History and Technology **15**: 7-29.
- [16] Edwards, P. N., S. J. Jackson, G. C. Bowker, and C. P. Knobel (2007). "Understanding infrastructure: Dynamics, tensions, and design." Report of a Workshop on "History & Theory of Infrastructure: Lessons for New Scientific Cyberinfrastructures", University of Michigan. <http://hdl.handle.net/2027.42/49353>. Accessed 12 June 2009.
- [17] Edwards, P. N., S. J. Jackson, G. C. Bowker, and R. Williams (2009). "Introduction: An agenda for infrastructure studies." Journal of the Association for Information Systems **10**: 364-374.

15 March 2010

- [18] Eisenhardt, K. M. (1989). "Building theories from case study research." Academy of Management Review **14**(4): 532-550.
- [19] Eisenhardt, K. M. and M. E. Graebner, "Theory Building from cases: Opportunities and challenges." Academy of Management Journal **50**: 25-32.
- [20] Farr, J. V. (2008). "Special issue on system of systems (SoS)." Engineering Management Journal **20**(4): 1.
- [21] Feldman, M. S. and J. G. March (1981). "Information in organizations as signal and symbol." Administrative Science Quarterly **26**(2): 171-186.
- [22] Ferris, T.L.J. (2007). "Systems engineering process standardization and cultural diversity." 2007 IEEE International Engineering Management Conference, July 27-August 1, 90-95.
- [23] Garud, R. and A. Kumaraswamy (1995). "Technological and organizational designs for realizing economies of substitution." Strategic Management Journal **16**: 93-109.
- [24] Garud, R., A. Kumaraswamy, and V. Sambamurthy (2006). "Emergent by design: Performance and transformation at Infosys Technologies." Organization Science, **17**(2): 277-286.
- [25] Gasser, L. (1986). "The integration of computing and routine work." ACM Transactions on Office Information Systems **4**(3): 205-225.
- [26] Gerson, E. M. and S. L. Star (1986). "Analyzing due process in the workplace." ACM Transactions on Office Information Systems **4**: 257-270.
- [27] Gorod, A. and B. Sauser. (2008). "System-of-systems engineering management: A review of modern history and a path forward." IEEE Systems Journal **2**(4): 484-499.
- [28] Grasso, D. and M. B. Burkins (2010). "Holistic Engineering Education: Beyond Technology". Springer.

15 March 2010

- [29] Hall, A. (1962). A Methodology for Systems Engineering. Princeton, NJ: Van Nostrand.
- [30] Hepso, V., E. Monteiro, and K. H. Rolland (2009). "Ecologies of e-infrastructures." Journal of the Association for Information Systems **10**: 430-446.
- [31] Hobday, M., A. Davies, and A. Prencipe (2005). "Systems integration: A core capability of the modern corporation." Industrial and Corporate Change **14**(6): 1109-1143.
- [32] Hughes, T. P (1998). Rescuing Prometheus: Four Monumental Projects that Change the Modern World. New York: Vintage Books.
- [33] Jackson, S. J., P. N. Edwards, G. C. Bowker, and C. P. Knobel (2007). "Understanding infrastructure: History, heuristics, and cyberinfrastructure policy." First Monday: **12**(6). <http://firstmonday.org/htbin/cgiwrap/bin/ojs/index.php/fm/article/view/1904/1786> . Accessed 2 March 2010.
- [34] Jamshidi, M. (2008). "System of systems engineering – New challenges for the 21st century." IEEE A&E Systems Magazine: May, 4-19.
- [35] Johnson, S. B. (2003). "Systems integration and the social solution of technical problems in complex systems." The Business of Systems Integration. A. Prencipe, A. Davies and M. Hobday (Eds.). New York, Oxford University Press: 35-55.
- [36] Keating, C., R. Rogers, R. Unal and D. Dryer (2003). "System of systems engineering." Engineering Management Journal **15**(3): 36.
- [37] Kljajic, M. and M. Mora (2008). "The systems approach view from Professor Andrew P. Sage: An interview." International Journal of Information Technologies and the Systems Approach **1**(2): 86-90.
- [38] Kling, R. (1980). "Social analyses of computing: Theoretical perspectives in recent empirical research." Computing Surveys **1**: 61-110.

15 March 2010

- [39] Kling, R. (1987). Defining the boundaries of computing across complex organizations. Critical Issues in Information Systems. R. Boland and R. Hirschheim. London, Wiley.
- [40] Leveson, N. G. (1986). "Software safety: Why, what, and how." ACM Computing Surveys **18**(2): 125-163.
- [41] Martin, J. N. (2000). "Processes for engineering a system: An overview of the ANSI/EIA 632 standard and its heritage." Systems Engineering **3**(1): 1-26.
- [42] Miles, M. B. and A. M. Huberman (1994). Qualitative Data Analysis: An Expanded Sourcebook, Second Edition. Sage.
- [43] Orlikowski, W. J. and J. J. Baroudi (1991). "Studying information technology in organizations: Research approaches and assumptions." Information Systems Research **2**(1): 1-28.
- [44] O'Sullivan, A. (2006). "Why tense, unstable, and diverse relations are inherent in co-designing with suppliers: An aerospace case study." Industrial and Corporate Change **15**(2): 221-250.
- [45] Pipek, V. and V. Wulf (2009). "Infrastructuring: Toward an integrated perspective on the design and use of information technology." Journal of the Association for Information Systems **10**: 447-473.
- [46] PRINCE (2009). The Little PRINCE 2: Practical Guide to Project Management, and Managing Successful Projects with PRINCE 2, The Stationery Office.
<http://www.prince2.com/> and <http://www.tso.co.uk>. Accessed 12 June 2009.
- [47] Rhodes, D. & D. Hastings (2004). "The case for evolving systems engineering as a field within engineering systems." Cambridge, MA: MIT Engineering Systems Symposium, March.

15 March 2010

- [48] Rhodes, D.H., A. M. Ross, and D. J. Nightingale (2009). "Architecting the Systems of Systems Enterprise: Enabling Constructs and Methods form the Field of Engineering Systems." IEEE International Systems Conference, March 23-26.
- [49] Ribes, D. and T. A. Finholt (2009). "The long now of technology infrastructure: Articulating tensions in development." Journal of the Association for Information Systems, **10**: 375-398.
- [50] Ring, J. and A. M. Madni (2005). "Key Challenges and Opportunities in 'System of Systems' Engineering." Proceedings of the 2005 IEEE International Conference on Systems, Man, and Cybernetics, October 10-12, 2005, Hawaii: 973-978.
- [51] Rouse, W.B. (2005). "A theory of enterprise transformation." Systems Engineering, **8**(4): 279-295.
- [52] Sage, A.P. and Cuppan, C.D. (2001). "On the systems engineering and management of systems of systems and federations of systems." Information Knowledge Systems Management, **2**: 325-345.
- [53] Salvador, F. (2007). "Toward a product system modularity construct: Literature review and reconceptualization." IEEE Transactions on Engineering Management **54**(2): 219-240.
- [54] Sapolsky, H. M. (2003). Inventing systems integration. The Business of Systems Integration. A. Prencipe, A. Davies and M. Hobday (Eds.). New York, Oxford University Press: 15-34.
- [55] Stinchcombe, A. L. (1990). Information and Organizations. Berkeley: University of California Press.

15 March 2010

- [56] Star, S. L. (1989). "The structure of ill-structured solutions: Boundary objects and heterogeneous distributed problem solving." Readings in Distributed Artificial Intelligence. M. Huhns and L. Gasser (Eds.). Menlo Park, CA, Morgan Kaufman.
- [57] Star, S. L. and K. Ruhleder (1996). "Steps toward an ecology of infrastructure: Design and access for large information spaces." Information Systems Research, **7**: 111-134.
- [58] Swarz, R. S. & J. K. DeRosa (2006). "A framework for enterprise systems engineering processes." International Conference on Software and Systems Engineering and their Applications, Paris, December, 2006.
- [59] Sydow, J., G. Schreyogg, and J. Koch (forthcoming). "Organizational path dependence: Opening the black box." Academy of Management Review.
- [60] Valerdi, R. and H. L. Davidz (2009). "Empirical research in systems engineering: Challenges and opportunities of a new frontier." Systems Engineering, **12**: 169–181.
- [61] Williams, C. and Derro, M. (2008). NASA Systems Engineering Behavior Study. NASA Office of the Chief Engineer.
- [62] Yin, R. K. (2009). Case Study Research: Design and Methods, Fourth Edition, Sage.

Table 1 – Cases

<u>Case</u>	<u>US/ Int'l</u>	<u>Military/ Civilian</u>	<u>Project Length</u>	<u>Interviews (n=30)</u>
Alpha - The Alpha information system was created to support the communications and information needs of other government departments 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. 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. Then a reconfiguration of the larger organization occurred, focusing on developing a globally-consistent, standardized IT enterprise with a centralized primary budget and planning authority.	US	Military	> 20 years	Tier 1: 3; Tier 2: 1
Beta - Two separate, competing programs aimed at modernizing the software components for a major operations planning system were being merged into a single project, Beta. One was a decade-long program that focused on incremental improvements to, and upgrading of, the existing legacy system through a highly structured engineering acquisition process. The second used a more revolutionary, or “remove and replace,” approach based on an agile prototyping methodology to quickly develop new components.	US	Military	< 10 years	Tier 1: 4; Tier 2: 4
Gamma - The Gamma project was established to address challenges in 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. An integrated design and acquisition program was developed to span five Departments, each with different operational constraints. After more than five years, the program underwent a major reorganization and initial operational requirements were approved.	US	Military	< 10 years	Tier 1: 4; Tier 2: 0
Delta - The Delta information system was chartered to provide an integrated set of services supporting consultation, command, and control across global operations of an international alliance. Initially created to integrate information systems of two different Departments, Delta was 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 would be both coherent and flexible.	Int'l	Military + National gov'ts	< 10 years	Tier 1: 6; Tier 2: 0
Epsilon - An aging infrastructure and a projected two-to-threefold increase in system demand led to the creation of the Epsilon program to coordinate the efforts of six federal agencies to address these system needs. One federal agency was 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.	US	Civilian	< 5 years	Tier 1: 5; Tier 2: 5

**Table 2 – Infrastructure Consolidation by Case:
Enterprise Membership, Agonistic Tensions and Success**

<u>Case</u>	<u>Alpha</u>	<u>Beta</u>	<u>Gamma</u>	<u>Delta</u>	<u>Epsilon</u>
<u>Membership in Enterprise</u>	Voluntary	Mandated	Mandated	Voluntary	Mandated
<u>Interest/ Exclusion Tensions</u>	“...started ... pulling [things and people] together under one umbrella. Building an empire, did it pretty correctly..... They get an empire, but it’s also good for everyone else. Good for everyone to get and share data.”	“The scope of this endeavor is far beyond what – 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.”	“The original requirements were very ambitious from [the agency] – 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.’”	“We have some advantages over US or other nations - only one pot of money ... On the other hand, nations insist no sole-source procurement; need to support multiple types of equipment.”	“Different groups have very different motivations, everyone has their own objectives ... they don’t align.”
<u>Ownership/ Investment Tensions</u>	“The golden rule: ‘whoever has the gold, rules.’ ...so that’s why we changed - he got the money... started looking at how to build Enterprise. ”	“[Service research arm] wants to do all the development and take it all away from [the acquisition agency, which] thinks doing fielding only is dysfunctional and wants to do development too.”	“Gamma technology does not run on its own. It runs as part of someone else’s network.... Same hardware and software being used eight different ways, just by [Service branch], depending on their platform.	“Applications have to be developed by industry in a network environment; they can’t be developed in isolation. [and at the same time,] strategic partnerships (e.g. Microsoft) are not under our control.”	“It’s all about saving money, but they don’t say ‘it’s saving industry money’.”
<u>Engineers’ Evaluation of Success</u>	Relatively successful, especially historically	Failed Consolidation	Serious problems warranted top down re-org to establish control	Relatively successful so far, but still early	Struggled initially, some signs of progress, still early in development life-cycle

Table 3 – Pacing Tensions

Case	
Alpha	“The culture is changing, but only because I think [leader X] and [deputy leader Y] have stayed there long enough if people don’t see the value, they will slow roll you”
Beta	“We knew it was unreasonable under the timeline that was planned – that was plainly obvious to folks.”
	“The acquisition system doesn’t support IT acquisition well, the testing process alone is too long”
Gamma	“Q: How does your program deal with changing requirements and constraints?” “A: Daily. [grin]”
	“A version is out of date before it hits the street. ... evolution is moving beyond requirements too quickly to keep up. You’re always chasing what the [technology] should look like.”
	“It’s Mr. [X] and it’s a shame he left the government. 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.”
Delta	“The only thing that is constant in our world is changing requirements”
	“Have been at [Agency] for about 15 years, and it has taken 15 years to develop the background to be able to do this job. ...security, legacy, people, process management, project management; so many issues you have to take into account.”
Epsilon	“Too much too fast.”
	“Our government institutions’ set up is not conducive for fast decisions ... sharing, collaborating, budgeting, etc. [are] very, very hard ... Each organization has their own budget process, their own speed bumps, etc... congress is very critical.”

Table 4 – Capabilities for Modularization and Integration

<u>Case</u>	<u>Modularization Capabilities</u>	<u>Integration Capabilities</u>
Alpha	“One of the most fundamental modularization practices is breaking existing large systems and networks into smaller chunks of technologies...”	“I think there were quite a few government representatives that – once they bought in, that they were going to have a round table and they were going to use it – everybody went along....”
Beta	“Strategy is to experiment with technology capability and process to further command and control process and systems. Procedure 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 [government agency Chief of Staff].”	“ Integrated schedules which list all activities needed for each 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 information. Architecture system diagrams to show this -- diagrams to monitor and configure activities.”
Gamma	“I believe COTS could meet 80% of the Increment 1 requirements already and [we could] have it out there in two years.”	“We have a great Risk Process . We have monthly meetings with the technical teams’ leads. Each team has a risk representative that meets with risk representative group . They input the risks in a database and if it is a big enough risk it goes to the RRB (Risk Representative Board) . They then decide what to do. They use a Risk Navigation Tool to track the risks.”
Delta	“They are following an evolutionary approach in which they’re breaking the larger set into sub-projects and phases of projects, shortening the time to avoid requirements creep...”	“At the project level, there are one or more Integrated Project Teams (IPTs) . IPTs are a coordinating vehicle with the end user committee. They hold formal meetings , develop documents for decision points, are responsible for quality assurance and project assurance process. ”
Epsilon	N/A (already modularized at outset – separate systems in separate agencies)	“The CONOPS is probably the most important practice we have.... The CONOPS puts a stake in the ground... The CONOPS served the purpose of articulating a vision ... and served as a vehicle of departure (‘I subscribe to this,’ or ‘I don’t’). ... put down, in one place, all those innovative ideas about the future ... system.”

Table 5 – Ambidextrous Roles and Influence Skills for Enterprise Systems Engineering

Case	Ambidextrous Roles	Influence Skills
Alpha	“[FFRDC] is on both sides of the house – [agency A] and [Agency B]”	“How do we influence this ...”
Beta	“There are 18-20 [service branch] men and women. [Our FFRDC] program is currently allocated 12 staff equivalents or years of engineering support. Plus 15 other government contractors who look to me as lead engineer.”	“We were able to influence them Many of the things that were put together to guide his decision were put together by us”
Gamma	“Twice a month we meet with all the staff on the program to discuss issues of common interest. Benefit there is a shared awareness of the program across all of [FFRDC]. People all of a sudden realize that people on one side of the company are working on the same problem ...share, meet and provide better support for customer.”	“We’re a little broken in my mind. Some you can still influence.” “Encouraging collaboration, sharing data and working with others whenever possible.”
Delta	“One of the crucial aspects is the cooperation approach. Even though we have the authority, the cooperation. It’s really an enterprise-wide approach and not one focused on a personal agenda type of program.” “We do not compete with industry ...Want to be preferred first choice. Unbiased. Not trying to sell a nation’s first choice or a nation’s solution.”	“Make sure [customers] understand, feel ‘in control’ or at least part of the decision-making process, and therefore that their budget is well-spent. publish metrics. That we are on target and producing expected quality... Eventually (once they trust us) they tend to withdraw and focus on other projects. I like to keep them involved, for changes later.”
Epsilon	“On one hand we want to make sure the products are built well – but we don’t have responsibility to build products. We sometimes have to rescue other contractors.”	“We tried to look ahead and find opportunities and [customers’] needs and things that were not necessarily on their horizon yet. Trying to forward position ourselves to be ready to talk about those needs early. If we had that, we can influence them and lead their decision-making process. Trying to position ourselves strategically in different positions in content, in different domains, engaging different leadership, having broad coverage to influence decision-making from our different roles.”

APPENDIX A: Interview Protocol

Thank you for agreeing to participate in this interview. It is part of a joint MITRE-MIT research study that leverages social science to help define the discipline and advance the practice of “enterprise systems engineering.” *[hand them copy of one page description of research project]* Enterprise systems engineering encompasses and enriches traditional systems engineering as it is practiced within a broader enterprise environment. <Program name> has been identified as good cases for this study. Your participation in this interview is voluntary. You may skip over any questions for any reason and you may stop at any time. Would you be willing to sign this consent form indicating you agree to participate in the interview? *[hand them consent form]*

- A. Would you please tell me the name of the organization you now work for, your current position, and give me a brief overview of your role in the work of <program name>?
- B. What is your Program Strategy? and what stage(s) are you in currently (planning, implementing, fielding, maintenance/evolution)? What is your development and fielding strategy and to what extent are you using prototypes, experiments, and betas?
- C. What engineering processes do you use?
 - How do you do requirements?
 - How do you do software design?
 - How do you do software development?
- D. What is your program's organizational approach (including government and contractors)?
- E. How does your program deal with changing requirements and constraints?
- F. How do you work with your stakeholders? Please discuss your internal stakeholders, external stakeholders, and relationships with competitors and other programs.
- G. If you had to pass this project off to someone tomorrow, what (one thing) would you want them to know?
- H. Is there anything else you'd like to tell me/us about the program or its current context?