FINDINGS OF CASE STUDIES IN ENTERPRISE SYSTEMS ENGINEERING

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Abstract - The systems engineering community is increasingly facing challenges of engineering enterprises that consist of many interrelated systems without a single hierarchical control authority. Although there are technical papers describing such complex adaptive systems as well as some early papers contributing to the theory of systems engineering of enterprises, there is no generally accepted theory or set of best practices. This paper presents the findings from over a dozen case studies in enterprise systems engineering conducted at the MITRE Corporation during 2005 and 2006. The projects studied were related to the US Air Force's Command and Control (C2) enterprise which is being engineered through many different programs by different contractors for different immediate customers - yet is expected to work as an integrated C2 enterprise. However, the findings presented are applicable to any net-centric enterprise with multiple users, operators and stakeholders.

Keywords: Enterprise Systems Engineering, Enterprise Management, Case Studies.

INTRODUCTION

Establishment of an ESE Focus Group

In October 2004, The MITRE Corporation's Command and Control Center established an Enterprise Systems Engineering (ESE) Focus Group, based on the recognition that systems engineering was advancing beyond traditional approaches in order to more effectively address the complex nature of today's systems, their acquisition and development, and their target operating environments. At the same time, complex systems theory was evolving and seemed to align with new systems engineering techniques that were yielding improved results in delivering operational capability. The ESE Focus Group was formed to document these new approaches and techniques, and therefore further advance the practice and theory of systems engineering to address complex, enterprise-level issues.

Five ESE Processes

The focus group's first year's activity produced an overarching model for ESE and a set of five ESE processes: Technology Planning (TP), Capabilities-Based Engineering Analysis (CBEA), Enterprise Architecture (EA), Strategic Technical Planning (STP) and Enterprise Analysis and Assessment (EA&A). The ESE Model integrates Traditional Systems Engineering (TSE) and the ESE processes into a single construct [1-4]. Both the model and its processes are based on analysis of purposeful systems [5], [6] and first principles in theories of complexity and enterprise evolution [7]— in particular, variety, shaping and selection. The five processes discussed in the "ESE Processes" section help shape the technical environment in which evolution takes place and interact with engineering management and TSE processes.

Eighteen Case Studies

In the second year, the ESE Focus Group turned toward conducting a set of case studies that would explore the utility of the derived ESE processes. A total of eighteen case studies were commissioned. Each investigated the applicability of one or more of the ESE processes to tackle an existing enterprise challenge and/or fulfill a critical enterprise capability need. The case studies were deliberately constructed to provide a wide range of projects, from Command Center operations to surveillance and situation awareness, to logistics and support. Some looked retrospectively at individual programs to evaluate how ESE concepts may have played a role in shaping program outcomes (even if the program's Chief Engineer may not have knowingly done so), and some were forward-looking, testing how the processes might affect program performance. Thus, the theory and practice of ESE were linked.

The participants on each case study were working level engineers, project managers and systems engineering managers. The Focus Group asked each of the participants to examine the degree to which the processes were used or might be used in their programs. They further asked them to discuss any enterprise-level processes they may have found useful in their engineering activities. They provided toolkits [3], conducted tutorials on the processes, set up document share sites and met quarterly as a group to share findings and perspectives. The objectives were clearly stated to improve program performance through the application of ESE and to improve the ESE processes through feedback as a result of its application. To encourage candor in the analysis, the focus group established a ground rule that the programs would not be named in any public forum. The results clustered around a number of common findings discussed in the "Summary of Findings" section.

ESE PROCESSES

TSE processes are used to organize the work routines of an engineering organization to provide order, and thereby increase the efficiency by which systems are produced and delivered. However, today's systems are being conceptualized and designed for more functionality and much higher degrees of integration to support increasingly complex interactions among people, processes and technology at an enterprise scale. Today's systems are also being called upon and designed for future operational environments in which dynamic threads of functionality are put together to serve an immediate need and then go away just as quickly. As a result, TSE thinking and processes have had to evolve toward ESE, in order to address the more complex and adaptive nature of systems and their interplay with their environments. ESE must balance the need to exploit today's best technologies and applications, while allowing for flexibility and adaptability in the exploration of innovation based on new combinations of existing technologies as well as those technologies yet to be discovered. Additionally, ESE must leverage complexity to achieve both effectiveness and efficiency within the enterprise as a whole. [11]. These principles are at the heart of the five ESE processes described below.

Capabilities-Based Engineering Analysis (CBEA)

CBEA operationalizes the goals and vision of the enterprise. It focuses on development of capabilities, grouping capabilities into enterprise capability portfolios and defining strategies to achieve those capabilities by addressing the complex inter-relationships among the portfolio systems. CBEA also involves the development of capability-based roadmaps to support the purposeful evolutionary development of systems, technologies, and new acquisitions to fulfill capability needs. [1], [3], [8].

Enterprise Architecture (EA)

EA captures the enterprise vision, strategy and implementation approach, and as such, represents the highest level of guidance or framework for enterprise evolution. EA describes the enterprise components, their roles and their relationships. It promotes self-synchronization for both developers and managers. It comprises the steps for developing a set of products to characterize the enterprise based its goals, effects and emergent properties; its component systems and elements; and the interactions of people, process and technologies among those components. [1], [3], [9].

Enterprise Evaluation and Assessment (EA&A)

EA&A helps shape the environment that causes competing options within an enterprise to flourish or perish by (continuously) characterizing progress toward enterprise goals. EA&A is a key part of the learning and control dimension of any enterprise. It is the primary means by which the technical dimensions of the enterprise are coupled with business decisions by providing analytical insights into the operational outcomes of those decisions. [1], [3], [10].

Strategic Technical Planning (STP)

STP sets the technical strategy for the enterprise. It establishes the balance between standards & competing technologies, and represents a shared technical image for the enterprise. To promote social learning of the enterprise as a whole, the shared image must be simple, comprehensible and straight-forward. Therefore, the STP should be limited to a few key technical objectives that can be used to guide enterprise development comprehensively.

Technology Planning (TP)

TP explores and exploits enterprise solutions through technical innovation and integration opportunities in both the commercial marketplace and research communities. Exploration favors innovation, and exploitation favors integration. TP seeks to evolve the enterprise by monitoring technology trends in both arenas. It identifies novel ways to combine those trends to ensure that promising technologies are made available and that they are sustainable in the current and evolving enterprise environment.

The ESE processes discussed above interact with each other to support various ESE activities. Figure 1 presents the interrelationship of these processes in the evolutionary context.

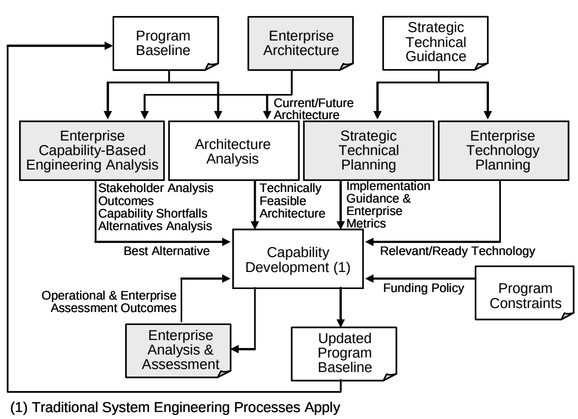

Figure 1. ESE Processes in Perspective

SUMMARY OF FINDINGS

In terms of general findings, there was agreement across most of the case studies that the ESE processes described here were very useful in guiding the steps involved in enterprise level engineering. It was also noted, however, that many of the studies did not use the processes completely or sequentially, but rather pulled from them as needs arose. An additional process for Stakeholder Analysis also proved very useful on a number of programs reviewed in the studies and in other cases, its absence proved detrimental to the engineering effort overall—highlighting the need for yet a sixth ESE process. A number of other common findings related to the important utility of up-front capabilities-based engineering, engineering architecture and the important role of integrating technology planning into a program's business processes to ensure successful enterprise. There was agreement throughout the study effort that enlightened systems engineering must account for social, cultural and economic variables if it is to be successful. This result has broad implications for systems engineering theory, practice and education. A more detailed summary of these and other findings is provided below.

The ESE Processes are Useful in the Practice of Complex Systems Engineering and Complements TSE

The case studies validated that the five original ESE processes and their associated toolkits provide useful guidance to inform enterprise systems engineering. Many participants noted that the processes especially offer a methodology to facilitate evolutionary development/delivery of enterprise capability in a complex environment of people, processes and technology. Many of the skilled systems engineers involved in the studies had used one or more of the methods instinctively in performing their jobs, especially in complex environments, but agreed it was beneficial to have them written down. Nevertheless, while the ESE processes proved useful, they did not obviate the need for TSE. The studies also found that traditional methods are still powerful and necessary tools for those parts of the enterprise for which requirements are known or control is assured.

Stakeholder Analysis is a Logical Sixth ESE Process, and an Important Enabler to ESE is Active Stakeholder Participation.

Understanding stakeholders' equities in the broad context of enterprise outcomes is essential. The reality of complex adaptive systems is that are multiminded. To achieve consensus and/or resolve conflict, we must understand that reality and devise interaction mechanisms that bring about convergence. The studies found that programs that addressed stakeholders and their needs, generally were successful. Those that did not, generally were not. See [11] for details of Stakeholder Analysis.

ESE Does Not Follow a Linear Path

The case studies showed that people did not use the ESE process steps following a sequential path, but in fact, often varied the ordering of steps depending on the nature of the enterprise objective or challenge at hand. At different times in the evolutionary process, people used different parts of the processes with great variability across the studies. More ESE "use cases" are needed to gain an understanding of which process parts are best applied to which situation.

Effective ESE Requires a Deliberate Investment of Resources Above the Scale of Individual Systems

In many of the case studies, participants reported it was essential to make investments above the systems level. This was especially true for support for up-front CBEA, STP, active collaboration among key stakeholders (Stakeholder Analysis) and an agreement and means to establish an enabling infrastructure (technical, business, operational) to achieve enterprise outcomes. Often, these investments were not part of the program baseline.

Context is Key and Architecture Can Help

The application of ESE processes should be done within an established context that is based on enterprise objectives. A Profiler© tool has been developed for that purpose [14]. Context is used to inform programs of their role in supporting enterprise outcomes. This includes guidance on the set of ESE activities each program must implement, giving due consideration to program resources, and a collective understanding of the value proposition for applying enterprise processes at the program and enterprise level.

Many case studies validated that EAs are effective tools for communicating intent and synchronizing stakeholders. However, the level of detail and partitioning for so-called EAs (more usually seen as Federated Architectures), often vary widely. While architecture is noted to be a powerful tool, the right partitioning and scale to support enterprise level operations is not yet clear.

Many architectures were done after the fact or as a perfunctory requirement. One comment was very telling, *"We did not use the architecture at all in the design, but it was extremely useful in talking to the stakeholders."*

ESE Must Look at the Interdependency of People and Processes that Result When Innovation is Introduced Within an Enterprise

Technology alone did not produce new enterprise behaviors (operational capability). It had to be shaped by the operational vision embodied in the Capabilities-Based analysis and assessment. Choices of candidate technologies were informed by "cues" from the enterprise environment (both commercial and military). Winning technologies were selected through a competitive process. Technology planning was less about investment in technologies that are needed and more about combining existing technologies in new ways. The evolutionary forces of variety, shaping and selection are driven by the interplay of people, processes and technology.

Strategic Technical Plans Can be Pervasive and Effective

The Strategic Technical Plan consisted of a handful of guidelines for the systems being developed, and as a result, the Chief Engineers relied heavily on it as an effective vehicle for co-evolution of the various systems in the enterprise. The Strategic Technical Plan consisted of simple "net-centric" rules like building a layered architecture, posting data to the network before processing it, using the Internet Protocol (IP) as a so-called strategic convergence protocol, publishing data in XML format and taking advantage of other web technologies, such as capability using a Service-Oriented Architecture.

ESE Requires New Socio-Cultural Skills

We see throughout many of the case studies an assertion that effectively carrying out the engineering of an enterprise requires not only new engineering processes, but also new socio-cultural skills. Leadership, strategic vision, conflict management, balancing cooperation and competition, coalition building, all became essential to address the dependent variables associated with operational, business and technical aspects of the system. Enterprise solutions depend equally and inextricably on technical, social and cultural variables. They cannot in general be separated. Both cross-organizational teams and Communities of Interest proved to be helpful in several cases.

Opportunity is the Other Side of Risk

Most of the programs had a risk management strategy based on TSE principles. Risk mitigation techniques focus on minimizing uncertainty in the outcome. Risk mitigation is about minimizing the probability that some desired outcome will not be achieved. But in complex systems, it is not always possible to predict the course of events – the system dynamics change as the system is designed – sometimes because of learning, sometimes because other people, processes and technologies adjust as a result of your strategy. In many cases, Opportunity Management played an equal role to Risk Management [12]. At least one program took advantage of this. They built a successful integration facility for their program. However, as it gained notoriety within the larger enterprise, they shifted its purpose and expanded it to become an enterprise resource.

SUMMARY AND RECOMMENDATIONS

The case studies highlighted the present state of ESE in one center of a company that has systems engineering as a core competency. It offered insights that could be applied to other centers within the company as well as to the systems engineering community as a whole.

Through this effort, *we* discovered that the five ESE processes provide the basis for a practice to support enterprise-level systems engineering. We also learned there is a need for a sixth process, Stakeholder Analysis -- another important activity for engineering an enterprise, especially those that involve a broad, diverse set of stakeholder interests. The case studies further revealed that successful enterprise systems engineering goes beyond establishing a core set of processes, however, and requires new skills that emphasize collaboration and the ability to establish the enterprise context for all stakeholders, balancing competing and cooperative interests and behaviors that can impact enterprise outcomes. ESE also requires new perspectives and the resources necessary to continuously scan the external environment and the interplay of political, operational, economic and technical factors in the development and delivery of enterprise capability. Finally, ESE demands a new understanding of the likely use cases through which ESE process steps may be applied, recognizing that ESE processes are not necessarily applied sequentially, but in varying steps depending on the enterprise context and objective.

In light of these case studies, we have several recommendations for the systems engineering community interested in the evolution of complex adaptive systems:

1. Build a set of ESE process toolkits within the professional community environment, e.g., through INCOSE or GEIA working groups. Focus on the six ESE processes outlined here (i.e., including the addition of Stakeholder Analysis). Build them from the perspective of purposeful systems [6] and evolutionary theory [7].
2. Build and promulgate a set of tools to support these processes.
3. Document and publish ESE use cases illustrating successes and failures in the application of the processes and how they interact. This would lead to learning and process improvement.
4. Advocate the need for ESE with both customers and senior management. There is ample evidence that the traditional planning and control paradigm beaks down in developing (evolving) complex systems. We as a community need to carefully articulate when TSE processes are applicable and when ESE processes are needed.

5. Support education and training in ESE. MITRE has partnered with several institutions interested in developing the theory and practice of ESE: MIT, Johns Hopkins, University of Vermont, The University of California at San Diego (UCSD), Stevens Institute, as well as organizations like IEEE, INCOSE and the New England Complex Systems Institute. Indeed, the systems engineering community as a whole must support education and training in ESE so the next crop of systems engineers will be able to meet the complexity challenges before us.

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