Enterprise Systems Architecting: Emerging Art and Science within Engineering Systems

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Abstract. With the growing complexity of systems, there is a corresponding increase in the complexity of the enterprises that develop, operate, and sustain such systems in an increasingly global environment. This drives the need to take a broader view of enterprises as systems in themselves to which we must apply the principles and practices of architecting. The current practice of Enterprise Architecting has been a significant contribution to creating and sustaining modern enterprises; however, we feel the current field is not a sufficient approach to the enterprises of this new century. A broader and more holistic approach is needed in context of an engineering systems perspective, drawing on the emerging systems architecting field, and taking into account new paradigms and environmental drivers. In the paper, we propose *Enterprise Systems Architecting* as an emerging art and science within the field of Engineering Systems. We discuss our present research focus, as well as some of the promising research being done by others that can contribute to this emerging area.

INTRODUCTION

Enterprises are complex, highly integrated systems comprised of processes, organizations, information and supporting technologies, with multifaceted interdependencies and interrelationships across their boundaries. Understanding, engineering, and managing these complex social, technical, and infrastructure dimensions are critical to achieving and sustaining enterprise performance. What then are the key attributes of the successful enterprise, both today and emerging? What are the key concepts, elements, and interrelationships that comprise the enterprise "system"? What is involved in "architecting" and "engineering" an enterprise to achieve desired characteristics in context of environment, business model, and associated product system?

Enterprises have long been studied by management scientists and social scientists; however, this has largely been through taking one single view of the enterprise such as studying the organizational structure or the information architecture. *Enterprise Systems Architecting* is a new strategic approach which takes a systems perspective, viewing the entire enterprise as a holistic system encompassing multiple views such as organization view, process view, knowledge view, and enabling information technology view in an integrated framework. In early work in this field, Rechtin (2000) proposes the principles of systems architecting as extensible to architecting organizations. Additional works (e.g., Bernus, 2003) describe information enterprise architecting with some extension to organizational factors, while others describe a process-based view. Further, some general frameworks and models for architectures to describe enterprises have been developed.

The current *Enterprise Architecting* practice is well established today and has clear extensions from software architecting practice. The prevailing view tends to be information technology centric, and it works well for the simpler enterprises trying to align processes and technology with organizational structure. As the enterprise moves from simple organization to a complex networked organization (an extended enterprise), we assert that an enriched view is needed. Further, we believe that this art and science needs to be more highly integrated with strategy and culture, and we require some new lens with which to view the enterprise. To differentiate our approach from the current enterprise architecting theory and practice, we use the term ***Enterprise Systems Architecting***. This enriched view focuses our research efforts on evolving a more extensive art and science viewing enterprises as true systems with emergent system properties. Our research has an overarching goal of predictability of enterprise systems in context of the larger engineering system which includes product system, enterprise system, and environment. Our paper will cover four major topic areas:

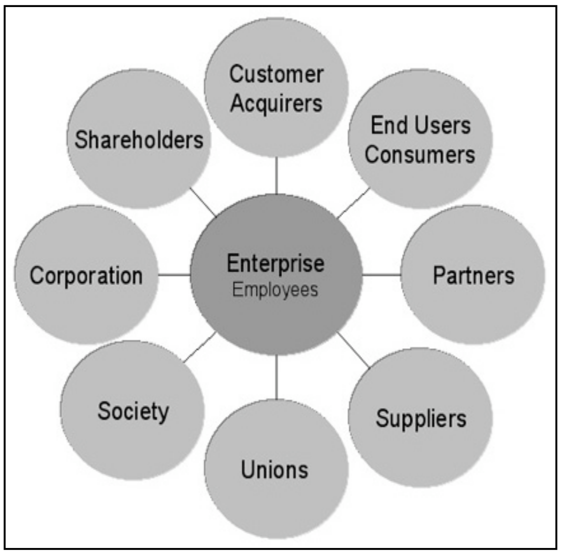
1. Enterprises as Systems
2. Architecting as an Art and Science Applicable to Enterprises
3. Current Field of Enterprise Architecting
4. Enterprise Systems Architecting as an Emerging Art and Science

ENTERPRISES AS SYSTEMS

We believe the study of the complex issues of modern enterprises are best considered in context of the overall "engineering system" that is comprised of the enterprise, products produced by the enterprise, and its environment. *Engineering Systems* is an important new field of study focusing on the complex engineering of systems in a broad human, societal, and industrial context. It takes an integrative holistic view of large-scale, complex, technologically-enabled systems which have significant enterprise level interactions and socio-technical interfaces. The establishment of this new field has been a significant step toward evolving the holistic engineering-management science needed to address the complex systems challenges of this century. Hastings (2004) describes the four underlying disciplines for engineering systems: (1) systems architecture/systems engineering and product development, (2) operations research and systems analysis, (3) engineering management and (4) technology and policy. The engineering systems field includes the study of enterprises, and all of the four underlying disciplines are involved in designing, developing and sustaining enterprises. In regard to the first of these disciplines in context of enterprise, we are concerned with enterprise architecture, enterprise engineering, and development of the enterprise elements – including organizational structure, processes, knowledge management, and enabling technologies. This paper proposes *enterprise systems architecting* as the essential approach to realizing an enterprise which can perform optimally within its environment to produce and deliver the desired product system.

Enterprise systems can not be separated from their environment and associated product system. Sussman and Dodder (2002) use the term "nested complexity" to describe a physical system embedded in a policy system. In studying any engineering system, it can be seen that the product system (that is, what gets delivered to the stakeholders) and the enterprise system are truly intertwined, along with the overall environment in which they reside. An established enterprise will innately influence any new product system that is produced by that enterprise. Similarly, the characteristics of a product system to be developed will drive the enterprise architecture toward a particular structure and set of behaviors. Thus, in enterprise architecting we are faced with an important consideration: How do you architect an enterprise that can most effectively produce a desired 'product system'? Today we can, at best, cite heuristics and emerging principles on how enterprises should be architected. Current research in enterprise systems architecting is working toward transforming enterprise architecting from an art to a science, wherein enterprises can be predictability architected and engineered.

Rhodes (2002) describes the global environment of this century as demanding a deeper understanding of national and cultural policies, economies, laws, priorities, and preferences. There is a growing need for enterprises to address integrated multiculturalism, and to apply systems perspectives and solutions toward addressing the key global challenges of sustainable development, including world peace and international security, management of natural resources, health systems, and many others. Within the context of this global environment and the challenges faced, enterprises are increasingly driven to consider an expanded set of factors, for example, the social and ecological impacts of decisions and action. Enterprises face complex interaction of multiple advanced technologies, and embedded intelligence that will allow further automation of complex organizational processes. Growth in international cooperation/merging of defense, information technology, communication, transportation, energy, and many other sectors will result in international extended enterprises developing systems of unprecedented size and complexity. Enterprises are also experiencing an evolution in how the people within an enterprise work together, with increased teamwork, distance collaboration, and telecommuting.



The new enterprises that are evolving are highly complex and the management approaches applied are shifting from the modern to postmodern, as described by Hughes (1998). There are many aspects of an enterprise system that must be considered, including: political, cultural, legal, economic, environmental, technological, sociological, psychological, geographical, and temporal. In any complex enterprise there are multiple ***stakeholders*** (Figure 1). Freeman (1984) defines a stakeholder as '*any group or individual who can affect or is affected by the achievements of the organization's objective'*. The stakeholder set involved in the design, development, and sustainment of modern enterprises is large and represents many diverse perspectives. Evolving a shared value proposition for the enterprise is a significant challenge.

While enterprise principles initially focused heavily on the customer, more recent enterprise research has revealed that the critical success factor for today's enterprises is to *balance* the needs of *all* stakeholders. It is critical that these multiple stakeholder views and contributions to the enterprise be considered in its design to achieve desired performance objectives. Even with a broader focus at the enterprise level, the *customer* can be a unifying force providing the ultimate means (revenue) for delivering the product to stakeholders. *Shareholders* provide capital and expect a positive return on their investment, enabled by ongoing innovation, growth, and profitability by the enterprise. *Employees* – including all levels of management and the workforce are another group of stakeholders, contributing effort and knowledge within the enterprise. This is the center of value creation, which these stakeholders provide in return for fair compensation, personal growth, pride, and various other tangible and intangible factors. A union, yet another critical stakeholder, may represent some employees. *Business partners* provide risk-sharing capital, intellectual property, and contribute to the enterprise's products or services in return for a sustained portion of the value created by the enterprise. *Suppliers* provide subassemblies, components, or services, and are concerned with mutually beneficial relationships. The number of suppliers and partners are many and varied, numbering in the thousands for large enterprises. The global networked environment provides new opportunities for partnering.

Finally, *society* is an important stakeholder with an interest that the enterprise maintains the environment, provides job opportunities, supports the tax base, and serves as a positive force in the community, the country, and even the global economy. Although customer satisfaction is necessary, it alone is insufficient to guarantee long-term success of the enterprise. The roles of these multiple stakeholders who interact with, contribute to, and derive value from the enterprise must be considered. This leads to new challenges and complexity for enterprise leadership. The number of stakeholders can be very large and, with each new stakeholder involved in the enterprise, the complexity of creating enterprise value will most likely increase. The challenge for an enterprise is identifying each stakeholder's unique needs and then balancing these in an optimal manner. In *Lean Enterprise Value* (Murman et al, 2002) a three-phased framework has been identified and is described in Table 1.

Table 1. Enterprise Value Framework

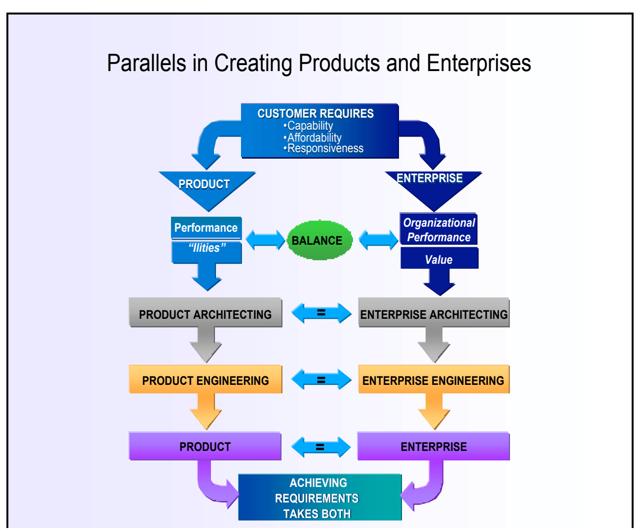
Phase	Purpose	Activities
Value Identification	Involves identifying stakeholders and their value needs or requirements, and includes dialogue on dimensions of value focused on ensuring that the team will be accomplishing the "right job".	Agreement on stakeholders their needs Prioritization of needs and interdependencies Current state of meeting needs Gaps between current and emerging needs Gaps in current state and known problems
Value Proposition	Needs of the stakeholders come together to form a shared value proposition through negotiating and aligning individual value needs, and developing agreements and incentive structures.	Surfacing complex issues Understanding areas for mutual gain Draft mission statements, agreements, 'contracts' Strategy for teaming and collaboration Convergence in perspectives
Value Delivery	Implementation phase, where value stream mapping and other improvement methods help to deliver value by ensuring the interconnection of activities in the value stream producing stakeholder outcomes. In this phase, focus is on "job is done right".	Implement lean principles/practices across value stream Align support systems to enable lean implementation Establish robust and flexible infrastructure

Enterprises must be viewed holistically as a complex integrated system. Enterprises do ***not*** lend themselves to the traditional decomposition approach to complex systems, as evidenced by looking at the processes in a typical enterprise. We see that just as product development cannot be effectively accomplished without the extensive involvement of other life cycle processes such as manufacturing, supply chain and customer, the enterprise processes must also cover a comprehensive set. Leadership and enabling processes, in particular organizational and information infrastructure issues, must all be considered in parallel and in an integrated fashion with the lifecycle processes needed to produce a product. Nightingale and Mize (2002) describe a generic process framework for a highly effective (lean) enterprise, as shown in Table 2. The framework is organized into three basic groups. Interrelationships and interdependencies of all of these processes must be understood and addressed in designing an enterprise.

Table 2. LAI Generic Lean Enterprise Process Framework

Life Cycle Processes ➢ Business Acquisition & Program Management ➢ Requirements Definition ➢ Product/Process Development ➢ Supply Chain Management ➢ Production ➢ Distribution and Support	Life Cycle Processes define the product life cycle, from initial conception through design, development, production and operational support. These are the value stream activities that contribute directly to the creation of products, systems, or services delivered to the enterprise's customers. These processes reflect the lean view of an overall product lifecycle within which functions serve, as opposed to the more traditional paradigm that allows each function to sub-optimize around its own operations.
Enabling Infrastructure Processes ➢ Finance ➢ Information Technology ➢ Human Resources ➢ Quality Assurance ➢ Facilities and Services ➢ Environment, Health, Safety	Enabling Infrastructure Processes support the execution of Enterprise Leadership and Life Cycle Processes. The enabling processes provide supporting services to other organizational units whom they serve as internal customers. Since they enable rather than directly result in enterprise success, they can be easily overlooked. In a lean enterprise, though, they are reoriented to support the 'Life Cycle Processes'.
Enterprise Leadership Processes ➢ Strategic Planning ➢ Business Models ➢ Managing Business Growth ➢ Strategic Partnering ➢ Organizational Structure & Integration ➢ Transformation Management	Enterprise Leadership Processes are developed and maintained by leadership to guide the activities of the enterprise. They cut across all of the entities that make up the enterprise. Enterprise leadership provides the direction and resources to break down barriers among and within Life Cycle Processes in order to create increased value to customers and stakeholders. They also provide the leadership to apply the Enabling Processes to improve responsiveness to the rest of the enterprise. Many of the leadership processes such as business models, strategic partnering, and organizational structures and integrations are highly significant in architecting enterprises.

Nightingale (2002) identified a number of significant issues in enterprise systems that require further study, analysis and research. Some general categories include: *standardization, integration, leadership and "enterprise engineering".* The challenges being faced include identifying the appropriate levels of standardization, integration, and collaboration across enterprises. How do we design, analyze, and research these crosscutting issues? Tom Peters (1982) introduced the term "loose-tight" in his analysis of excellent organizations. What processes, information, products, and organizations need to be "tightly" integrated/standardized versus those that should be more "loosely" controlled or



decentralized? Are new models of leadership required to achieve effective enterprises? Can enterprises be “engineered” (Figure 2) much the same as products are engineered (see Nightingale, 2002) such that there are parallels in building products and enterprises?

Standardization is rapidly becoming a key enterprise strategy for effectiveness and efficiency, and it is occurring across products, processes, technology, and information management. *Product* standardization has long been deemed effective to reduce total life cycle costs. At the multi-program enterprise level, corporate wide *process* councils have emerged in many large companies. These councils bring together groups across the enterprise involved in executing the same processes (for example, program management, product development, and supply chain management). The councils develop standard processes across the company, building upon the best practices that exist within the various organizational units or from outside the company. At the national enterprise level, the US Department of Defense instituted the Single Process Initiative (SPI) as part of the acquisition reform efforts of the 1990s. Prior to SPI, different DoD organizations had different process requirements for their contractors. A given contractor with multiple DoD customers would have to maintain multiple process standards that could be audited for compliance, an expensive and wasteful approach. Under SPI, a contractor facility was able to adopt a single process standard, which each DoD agency accepted. Additionally, many large companies are standardizing their *information and knowledge* management systems. For example, they are reviewing the numerous IT systems that have emerged as a result of mergers and acquisitions and determining which systems can be employed in common, often with centralized supporting infrastructure.

To create value efficiently, the enterprise elements - processes, information, organizations, and enabling infrastructure - need to be appropriately linked and integrated. There is a great tendency for organizations to function as a group of ‘silos’, with each sub-unit (for example, procurement or engineering) acting independently of the other sub-units. Often, sub-unit performance excels, but the enterprise as a whole fails to achieve its full potential. It is important to understand what elements require full *integration* versus *interfacing* and/or effective communication flow. Integrating information, organizations, and processes across multi-program and global enterprises presents further challenges.

With this brief introduction to enterprises, it can be clearly seen that the complexity of enterprises presents us with challenges that drive the need for increased analysis and synthesis before progressing to implementing the transformation (i.e., enterprise engineering) of enterprise systems. In the next section of the paper, we discuss the art and science of architecting and its applicability to enterprises.

ARCHITECTING AS AN ART AND SCIENCE APPLICABLE TO ENTERPRISES

Enterprise architecting is emerging as an important activity which is unique from “enterprise engineering”. This emergence mirrors the emergence of systems architecting from the field of systems engineering. The complexity of 21st century systems is driving systems architecting as an important discipline within systems engineering to the extent that it is sometimes now considered to be independent of systems engineering. Similarly, the complexity of 21st century enterprises is driving the need for enterprise systems architecting as distinct from enterprise engineering.

Central to this discussion is the need to define what we mean by architecture. According to Rechtin (2000), “information is architectural if it is needed to resolve the purposes of the client”. The IEEE P1471 Standard defines architecture as “the fundamental organization of a system embodied in its components, their relationships to each other and to the environment and principles guiding its design and evolution". The Systems Architecture Working Group of the International Council on Systems Engineering (INCOSE, 2000) defines architecture as "the fundamental and unifying system structure defined in terms of system elements, interfaces, processes, constraints, and behaviors". Maier (2000) notes that architecture is "the set of information that defines a systems value, cost, and risk sufficiently for the purposes of a system sponsor".

Enterprise architecting provides the strategies and modeling approaches to ensure that adequate time is spent in developing the possible 'could be' states, and evaluating and selecting the best alternative given a set of desired properties and criteria for the future enterprise system. In the case of already established enterprises, the enterprise architecting provides the approach for analyzing and understanding the 'as is' enterprise, and allows the various alternative changes and interventions to be analyzed. Enterprise Engineering provides the successful strategies and implementation approaches for transformation of an enterprise from 'as is' to a 'to be' state. As enterprise complexity rises there are many more possibilities to consider in designing an optimal enterprise, and so importance of architecting grows. In some respects, it is difficult to discern where architecting ends and engineering begins. Maier and Rechtin (2000) suggest an architecting-engineering continuum as shown in Table 3.

Table 3. Architecting-Engineering Continuum
adapted from: Maier, M. and Rechtin, E., The Art of Systems Architecting, CSC Press, 2000

Characteristic	***Architecting***	***Architecting & Engineering***	***Engineering***
Situation	Ill-structured	Constrained	Understood
Methods	Heuristics/Synthesis	Combined synthesis/analysis	Equations and Analysis
Interfaces	Focus on misfits	Critical	Completeness
System Integrity	Single Mind	Clear Objectives	Disciplined Methodology
Customer	Working for Client	Working with Client	Working for Builder
Issues	Confidentiality	Conflict of interest	Profit vs Cost

Through the emphasis on architecting, we look not just at transition from an 'as is' to the 'to be' state, but also at the underlying decision analysis related to considering the various alternative 'could be' states of the new (or transforming) enterprise. Architecting enriches the thinking about the enterprise through a deeper exploration of each enterprise view, and more importantly at the interconnections and interrelationships between these views. Decisions are made about the alternatives in context of the business model, technology strategy, culture, purpose, and other factors.

Architecting is both art and science, and the current state of systems architecting is probably more of the former. The 'art' uses qualitative heuristic principles and techniques including lessons learned, value, judgments, and soft measures. Increasingly, architecting is also becoming a science that uses quantitative analytic techniques including math, science, modeling, and measurement. Architectural design, according to Stevens, et al (1998) serves as "the conscience for an evolving system" by documenting the aspects that can and can not be changed without compromising system integrity. These authors note that architectural design "provides a level of abstraction which allows designers to reason about system behavior", and that "good architecture makes design intellectually tractable and exposes the issues most crucial to success". These objectives of architectural design are critically important to enterprise design and transformation.

Applying the art and science of architecting to enterprises is not a new idea. We have seen the evolution of this concept over the past decade or so, which has culminated in the present field of Enterprise Architecting. In the next section of the paper, we will provide a very brief overview of the current field and its practice. The growing momentum behind enterprise architecting can be seen in the number of new frameworks, books on the subject, and increasing number of commercial firms with enterprise architecting product and service offerings.

CURRENT FIELD OF ENTERPRISE ARCHITECTING

During the past decade, enterprise architecting has grown into a well-recognized field, moving beyond the early business process re-engineering focus to take a more in-depth view of the structure and purpose of an enterprise to develop a top-level conceptual design. One of the shortfalls of the current field of enterprise architecting is that it tends to take an information technology (IT) centric perspective. This has been driven by the large capital investments made in the last decade to insert enabling technologies into the enterprise organization in support of business practices and processes. There have been many architecture frameworks, standards, modeling languages and tools developed in support of creating and transforming enterprises.

Architecture Frameworks are standards for the description of architectures, and many such frameworks have emerged for enterprises. A framework defines the products an architect must deliver and how those products must be constructed – without constraining the product content. Frameworks use views to simplify the overall architecture into a set of useful perspectives that describe certain aspects of the whole. An *architectural view* is a perspective on a system (or enterprise) describing a related set of attributes, while viewpoints define the rules for creation and use of the views. Architectural views serve to isolate unique areas of focus or concern (e.g., process view), reduce complexity to help us understand the whole enterprise, and assist in providing unique perspectives to address the needs of the enterprise's diverse stakeholders. A number of different architecture frameworks for enterprise have begun to emerge, and the views vary based on the framework. An open question in enterprise architecting is "what is the optimal set of views used to describe the enterprise?"

Frameworks are important to enterprise architecting for a number of reasons. First of all, frameworks serve to codify best practices for architectural description of enterprises. They can also facilitate comparative evaluation of alternative architectures and facilitate collaboration of enterprise engineering teams by presenting basic architectural designs in a standard way. Frameworks and standards ensure that their sponsors receive architectural information in the desired format. They can also serve to enhance 'enterprise interoperability' by requiring interoperation of critical elements be described in a common way.

The many standards and frameworks for Enterprise Architectures that have emerged over the past decade include, for example: Zachman Framework; Department of Defense Architecture Framework (DoDAF); IEEE-Std-1471-2000 Recommended Practice for Architectural Description of Software-Intensive Systems; Perdue Enterprise Reference Framework (PERA); Computer Integrated Manufacturing Open Systems Architecture Framework (CIMOSA); Architecture of Integrated Information Systems (ARIS); many others. Bernus (2003) provides a comprehensive description of many of these frameworks, including the Generalized Enterprise Reference Architecture and Methodology (GERAM) for comparing enterprise frameworks.

Enterprise Architecting is a complex endeavor which drives the need for modeling, simulation, and visualization tools which can assist in the analysis and decisions that must be made. These tools can be powerful aides to comparing one 'could be' architecture to another. There are many commercial tools (for example, Metis®, Aris Toolset) which have come into the marketplace in recent years to assist with architecture visualization and modeling. Enterprise Modeling involves building a model of the enterprise and is concerned with assessing various aspects of an enterprise in order to better understand, restructure or design enterprise operations. Enterprise Architecture Visualization involves the use of software tools and advanced modeling techniques to create a visual and adaptable model of an enterprise. The importance of modeling and visualization methods and tools grows with the increasing complexity of the enterprise. Hyson (2003) has proposed a model to assess the readiness of an organization to do enterprise modeling.

Schekkerman (2003) has developed the Extended Enterprise Architecture Maturity Model (E2AMM[sm]) to provide a model to assess the enterprise architecting maturity on a zero to five level scale: no enterprise architecture (level 0), initial enterprise architecture (level 1), under development (level 2), defined (level 3), managed (level 4), or optimizing (level 5). His work is based on the Meta Group "Enterprise Process Maturity Model" and the Software Engineering Institute's capability maturity model concepts. Such a model is an important contribution to the current field, as it recognizes the complexity of enterprise architecting, as well as acknowledges the significant level of commitment and resources needed to address the enterprise system.

ENTERPRISE SYSTEMS ARCHITECTING AS AN EMERGING ART AND SCIENCE

Our brief overview of enterprise architecting has shown this as a well established field and practice, but is limited by its prevailing information technology-centric view. Enterprises are no longer simple organizations, but rather are often highly complex networked structures (an extended enterprise), and so we believe that an enriched view is required. Further, we believe that this enterprise approach needs to be more highly integrated with strategy and culture, and we require some new lens with which to view the enterprise. We are focusing our research efforts toward evolving a more extensive art and science viewing enterprises as true *enterprise systems*. To differentiate our approach from the current enterprise architecting theory and practice, we use the term ***Enterprise Systems Architecting***.

The enterprises of this century are truly systems in themselves and as such the properties and design issues for complex systems also relate to complex enterprises. The properties take two forms: (1) system properties and (2) soft emergent values. System properties are those that may be selectively targeted and may involve trade-off decisions which will optimize one or more of these properties over others. They may include: sustainability, scalability, flexibility, agility, stability, adaptability, robustness, and others. The second type, 'soft properties', are emergent values or qualities which are unique to enterprise systems as they extend from the human dimension inherent in the enterprise system. These may, in fact, serve as leading indicators of enterprise excellence (or possible failure). These properties include trust (or distrust), conviction, loyalty, and others. Another very interesting emergent quality is enterprise intelligence -- intelligence not just of the people, but the emergent intelligence of the people with enacted processes and aligned enabling technologies. Ring (2004) notes that by intelligent enterprise, "we mean that such an enterprise exhibits the ability to self-adapt to changes – in its context, internal capabilities, and stakeholder interests".

We are beginning to research how the various properties and behaviors of systems relate to enterprises, and how decisions on 'could be' architecture alternatives may be made based on optimization around a given property. For example, what enterprise architecture could maximize the long term stability of the enterprise versus what architecture would maximize the flexibility of the enterprise in regard to its ability to design innovative new products? Can a single enterprise model be 'optimized' for both such properties, or do we need to select for one over another?

One area under exploration that offers great promise is the management of uncertainty. The use of *real options theory* (de Neufville, 2004), for example, offers a new approach to providing intelligent decision options in design of systems. A far-reaching goal would be to develop the knowledge that is needed to be able to model enterprises in such as way that we can predict enterprise behaviors and outcomes to optimize around various properties, and provide the flexibility that will enable ease of change to the enterprise system in the future.

There are many interesting research questions related to enterprise architecting, and many of these have emerged out of attempts to transform enterprises to an improved state of performance. For example, the Lean Aerospace Initiative (LAI) is a consortium of stakeholders from aerospace industry, government, and MIT whose mission is to develop the knowledge and products to assist in the transformation of the aerospace industry to a lean enterprise. LAI has developed a series of transformation tools (e.g., Lean Enterprise Self-Assessment Tool (LESAT)) that aid in the total enterprise transformation process. One of the key elements in transforming to a lean enterprise is to define the "future" state of the enterprise, and this requires "architecting" the vision of the future lean enterprise in order to engineer the transformation path. LAI presently has three major areas of research including product lifecycle (product development and systems engineering), enterprise transformation, and enterprise architecting. Each of these three areas has contributions to evolve the holistic approach of Enterprise Systems Architecting. Research is already underway on a variety of topics and rapidly growing interest in enterprise architecting suggests there will be increasing emphasis on this area.

There are many general research questions that relate to the enterprise as a holistic system. As we have previously discussed, a fundamental question related to our view that enterprises are systems is: how do you architect enterprises to optimize around certain properties? Another interesting area to be explored is how the work on soft systems methodology by Checkland (1981) and others may apply to enterprise systems architecting. Rechtin (2000) proposes a number of heuristics for architecting organizations that may evolve to enterprise architecting principles. We are also interested in what enterprise behaviors may be modeled and ultimately if enterprise systems can (or can not) be predictably architected.

Viewing an enterprise system through architectural views leads us to a number of very interesting questions. For the organizational view, research has been initiated related to value delivery, and further research is need to answer such questions as: how do you organize to deliver best value to the full set of enterprise stakeholders in context of a given business model? Another area of high interest is what measures and incentives are most effective in context of enterprise structural and behavioral factors?

In regard to the process view, LAI researchers at MIT have begun to explore whether enterprises are more effective if processes are standardized and managed at the enterprise level. Biemans et al (2001) have researched the complexity of business systems architecting, and assert that "we will only succeed in mastering business processes despite their complexity if we instill a culture in which business process are modeled and analyzed before they are modified". Browning (2004) notes that "thinking of and modeling an enterprise as a group of constituent processes and activities, executed by organizational elements (and other tools), and resulting in product elements, is a helpful paradigm". The knowledge view is a particularly rich area to explore in complex enterprise systems where the enterprise knowledge is increasingly important yet more difficult to manage than in the past. For example, research is needed on how knowledge can be transformed for competitive advantage in the enterprise given the organizational culture and enabling technologies. The integration of knowledge across an extended enterprise that crosses individual single enterprise (e.g., company) boundaries is essential in complex enterprises emerging to develop, deliver, and sustain system-of-systems.

In taking an engineering systems perspective, we recognize that the product system and the enterprise system are intimately connected. The architecture of a future product system and the architecture of the enterprise which will design and produce it must be in harmony to achieve optimal results. Another type of essential harmonization is the intra-architectural harmony of the enterprise architecture. That is, the elements comprising an enterprise such as organization, processes, and technologies must be in harmony for optimal function. We see this as an interesting and yet unexplored area of research, with such important questions to be considered. What are the intangible qualities that will emerge in an enterprise that is well-architected (in harmony)? What makes an enterprise behave as a holistic system?

Within the Engineering Systems Division at MIT, we are actively exploring the education needed to prepare future leaders to architect complex enterprise systems. In 1998, Nightingale developed the MIT course “Integrating the Lean Enterprise” that is focused on the practical aspects of managing and transforming enterprises using lean principles and practices. In the Spring Semester of 2004, the authors are piloting a new doctoral level course which is focused on the evolution of *enterprise systems architecting* as an art and science. The students are active participants in shaping the future directions of an enterprise systems architecting research agenda, theory, and practice. Our course is helping to define the educational experience that is needed for engineering systems leaders to address the intricate relationship of product system and enterprise system in context of their overall environment.

SUMMARY

During the past decade, we have seen the evolution of the field of *enterprise architecting* which has led to the development of architecture frameworks, standards, modeling languages and tools. Within the various views of the architectural frameworks, researchers have contributed to the body of knowledge related to enterprises. An increasingly important issue is how to create the understanding, methodology, and interfaces to achieve balance across the multiple programs, stakeholders, and requirements of highly complex enterprise systems. For success in achieving customer capability, affordability and responsiveness it is imperative to consider a total enterprise perspective in context of the overall environment, as well as in respect to the product system it delivers. Enterprises, much like products, must be architected as complex integrated systems consisting of people, technologies, processes and information components. These must be considered in concert with each other and across various local and global enterprise levels, and in context of the total engineering system. We recognize that these complex enterprises exhibit systems properties, as well as have unique emergent values or qualities rooted in their human dimension.

Over the past five years, Engineering Systems has been evolving as an important new field of study that takes an integrative holistic view of large-scale, complex, technologically-enabled systems which have significant enterprise level interactions and socio-technical interfaces, and include the product system, enterprise system, and the environment. We view the development of the art and science of *Enterprise Systems Architecting* as an important contribution within the overall field of Engineering Systems, and it is perhaps the most unexplored territory in this emerging field. There is significant research ongoing at MIT and other leading universities across the globe that will serve to evolve this art and science, and more is needed to address the challenging research questions we face. In conjunction with this research, further work is beginning to determine how best to educate the future systems leaders who will design, build, manage, and transform complex enterprise systems to meet the systems challenges of this century.

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