

Enterprise Engineering: An emerging field and the ongoing research

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Abstract

The field of Industrial Engineering has changed over the years, and it has now evolved into Enterprise Engineering. This new discipline embodies the knowledge, principles and practices relating to the analysis, design, implementation and operation of an enterprise. We had defined enterprise engineering as the engineering process applied to enterprises. Consequently, one approach to understanding enterprise engineering is to view it as systems engineering. The PhD program in the Industrial and Systems Engineering at Florida International University provides integrated research and education in the area of enterprise systems engineering. The National Science Foundation, NASA AMES Research Center and local corporations have partially funded the department's research in this area. The primary ongoing research effort at FIU on enterprise systems is enterprise integration. Enterprise integration can be defined as the study of an organization, its processes, and resources, understanding how they are related to each other and determining the enterprise structure so as to efficiently execute the enterprise goals. This paper discusses the research conducted in enterprise integration at FIU.

1. Introduction

Enterprise Engineering is the systems engineering approach in which the system of concern is the enterprise. An enterprise is defined as an organization composed of interdependent resources (people, technology, infrastructure and machines) which must coordinate their functions and share information in order to achieve common enterprise goals. By this definition an enterprise is a socio-technical system; it involves people and how they are organized as well as the technology they employ. The Enterprise Engineer has to deal with how to design and improve all elements associated with the enterprise through the use of engineering and analysis methods and tools to more effectively achieve its goals and objectives. In this paper we show how enterprise engineering has emerged as a new discipline of study. Previous disciplines were narrower, only considering a few aspects of the enterprise. The paper discusses the history of enterprise systems and of how they have been studied. Also, An overview of the new Ph.D. program at FIU that focuses on enterprise engineering and the ongoing research in enterprise engineering is briefly described.

1.1 History leading to the emergence of Enterprise Engineering

The field of Industrial Engineering has changed over the years, and it has now evolved into Enterprise Engineering. The transition from craftsman to enterprise engineering took hundreds of years as seen in

Table 1. During this transition, in the early 1900's, Frederick W. Taylor was developing his theory of scientific management as the world was moving from an agrarian economy to a production economy. Taylor devised a system he called Scientific Management, a form of Industrial Engineering that established the organization of work. The outcome of this evolution is the emersion of Enterprise engineering as a new discipline. This discipline embodies the knowledge, principles and practices relating to the analysis, design, implementation and operation of an enterprise (Petrie 1992, Kosanke et al. 1999).

Table 1: Evolution of Industrial Engineering

Decade	Industrial Evolution	Description
1700's	Craftsman	Completely custom
1800's	English System	General purpose machines
1850's	American System	Precision and interchangeability
1900's	Scientific Management	Prespecified worker motions
1950's	Process Improvement	Statistical process control
1970's	Numerical Control	Precision/control of special purpose machines
1980's	Computer Integrated Manufacturing	CIM and robotics
1990's	Logistics	Supply-Chain Management
2000's	Enterprise Engineering	Enterprise, ERP, integration

Historically, the Industrial Engineering discipline focused on the shop floor. The scope broadened to include manufacturing processes. More recently the attention has broadened yet again to include logistics and supply chain management, focusing on processes both within and among production facilities, as well as upstream suppliers and downstream distributors. An even broader view is now emerging, which is the whole enterprise that deals with the understanding of how all the elements of an enterprise play together as well as how this understanding can be used to maximize value (Rouse 2004). But even this broader view of modern Industrial Engineering is too narrow. Networking, globalization, telecommuting and outsourcing are making the boundaries of enterprises harder to define; it is now more difficult to take apart the enterprise from account suppliers, distributors, customers, and other stakeholders in the economic and social environment.

The discipline of Enterprise Engineering builds upon several reference disciplines in science, engineering, and humanities, such as Industrial Engineering, Systems Engineering, Information Systems, Business Process Reengineering, and Organizational Design. Industrial Engineering is an excellent reference discipline for Enterprise Engineering as it promotes a holistic approach for the design, development, and implementation of integrated systems of people, machines, and materials (Badiru and Baxi 1994).. Furthermore, Industrial engineering has a unique focus, as well as extraordinary breadth since the industrial engineer functions at all levels of the enterprise. Because their skills can be used in almost any type of organization, industrial engineers are more widely distributed among industries than are other engineers. Industrial and Systems are, by far the most diverse set of engineering graduates in terms of Industries, positions, and career paths (Rouse 2004).

2. Enterprise Engineering as Systems Engineering

We had defined enterprise engineering as the engineering process applied to enterprises. An enterprise is a system. A system is defined as, "... an identifiable, complex dynamic entity composed of discernibly different parts or subsystems that are interrelated to and interdependent on each other and the whole entity with an overall capability to maintain stability and to adapt behavior in response to external influences." Consequently, one approach to understanding enterprise engineering is to view it as systems engineering. System are goal seeking and holistic, they have a hierarchy, they transform inputs into outputs, they consume and/or create energy, they are affected by entropy, and they have equifinality and feedback.

Enterprises by nature are goal seeking; they are rational and have a logical objective or purpose. In enterprises their goals are the strategies for being profitable. Enterprises must be analyzed holistically because they have emergent properties, behavior patterns are exhibited by the whole that cannot be discerned by any of the individual components. Enterprises are hierarchical, for example their organization is often described in a hierarchy of divisions, departments, and workgroups. Entropy is the natural tendency of systems to consume themselves and decay; it is also the measure of the degree of disorder in a system, consequently this affects enterprises. Enterprises have equifinality, which is the ability to reach goals in a number of different ways, and hence feedback is needed by enterprises to allow them to change directions. Lastly, enterprises as well as any other system create and/or consume physical and/or emotional energy to transform the inputs into the outputs, raw materials into products, energy into service, and the like.

Most research in enterprise engineering is limited to specific subsystems or perspectives. Research on subsystems takes the hierarchical view of the enterprise and decomposes it into subsystems and then the individual subsystems are treated individually. For example, you could analyze and design only the feedback system. There are several feedback systems in enterprises, the most predominant is performance measurement systems (Suwignjo et al. 2000). You could also define the subsystem as a process and analyze the process such as done in integrated product design and development (Joo and Barton 1995). You could also analyze the enterprise from a single perspective of the entire system. For example, you could analyze and design the entire enterprise from the data perspective only (Giachetti and Alvi 2001). Each of these research approaches have contributed to our knowledge and understanding of enterprise systems. However, there is also a need for holistic approaches that move beyond considering the subsystems in isolation. A holistic approach would consider the relationships between the subsystems and the impact on overall enterprise behavior.

There has been research conducted from this holistic perspective. The predominant research approach is the development of enterprise reference architectures that describe the enterprise from many different viewpoints. Reference architectures that have been developed include CIMOSA (AMICE 1993; Kosanke et al. 1999), GRAI (Doumeingts et al. 1987), PERA (Williams 1994), and GERAM (GERAM 1999; Bernus 2001). The reference architectures embody knowledge of what enterprise engineers should analyze and how they should analyze it. The reference architectures also decompose the enterprise. The favored decomposition is according to different views of the enterprise. For example, CIMOSA has four complementary views of function, information, organization, and resources. Whenever you decompose a system the problem is how to integrate or relate the analysis and design done of the subsystems. The reference architectures provide guidance on how to accomplish this.

A second research theme in enterprise engineering is the methodology to conduct the analysis and design (Batini et al. 1986; Doumeingts et al. 1987; Martinez 2000; Chalmers et al. 2001; Avison and Truex 2003; Truex and Avison 2003). In the methodology approach the goal is to embed knowledge in the approaches and the tools used to do the engineering analysis and design. Using well defined methodologies have been shown to improve the final system design.

3. Enterprise Engineering at FIU

Florida International University (FIU), Miami's public research university founded in 1972, is one of the youngest universities that has attained the Carnegie Foundation's top category of Research Extensive (formerly Research I) status. While most universities are very proud, and rightly so, of their history there is one advantage of being young – it allows you greater freedom to embark on new programs and to deviate from traditional disciplines of study. The Department of Industrial & Systems Engineering at FIU has taken this approach by focusing their Ph.D. program on Enterprise Systems Engineering. The curriculum combines elements of systems engineering, manufacturing engineering, information

technology, Industrial Engineering, and engineering management. The doctoral degree provides its students with the necessary tools and methodologies to achieve such approach.

Other universities have recognized the emergence of enterprise engineering but few have so squarely focused their curriculum on enterprise engineering. Some of the universities that have programs in enterprise engineering include the University of Texas at Arlington, New Jersey Institute of Technology, George Mason University, and Georgia Institute of Technology.

4. Enterprise Engineering Research at FIU

The primary ongoing research effort at FIU on enterprise systems is enterprise integration. There are two types of integration to consider in enterprise engineering. One is the integration of the multitude of viewpoints of the enterprise. This is the integration of the engineering analysis and designs done to sub-systems and perspectives. The second enterprise integration is the integration of the enterprise itself. The motivation for integrating the enterprise is that studies demonstrate that higher levels of integration lead to improved enterprise performance.

Towards studying enterprise integration we have developed a layered framework defining different integration types encountered in the enterprise (Giachetti 2004). The purpose of the enterprise information integration framework is to decompose the enterprise to reveal and define the integration types so they can be better understood. Figure 1 shows four levels of an enterprise system and the integration types at each level. The four levels are network level, data level, application level and process level. Each level contains objects that are more abstract. The levels, integration types and integration obstacles encountered at each level are described next.

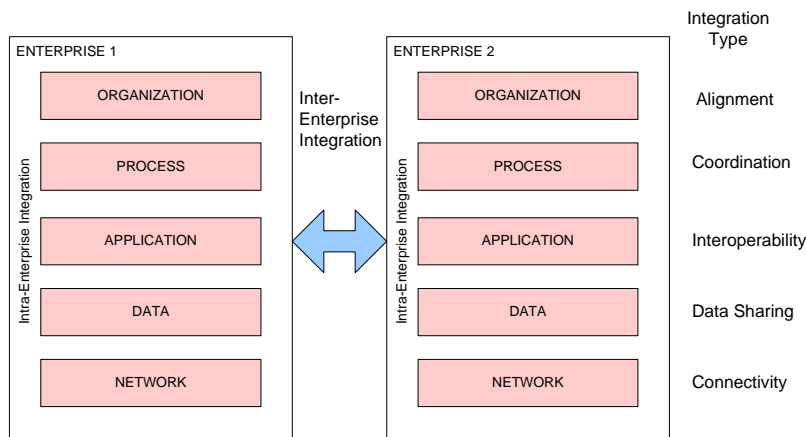


Figure 1. Enterprise Integration Framework

We consider five broadly defined subsystems each with its own specific integration issue to be addressed. The levels are termed: network, information, application, work processes, and organizational levels. In the following sentences we illustrate the level and its corresponding integration issue. But in this proposal we focus on the organizational, work process and application layers. At the network level, the integration issue is the *physical heterogeneity* of the hardware, machines, devices, and their operating systems found in a physical network. The integration goal at the network level is *connectivity* defined as the linkages between systems, applications, and modules. Level two, the information level, deals with the availability the data elements the enterprise system utilizes to complete its business functions. The integration goal is *information sharing* where two or more sub-systems or organizational units exchange information with each other. Information sharing requires agreed upon syntax and the users of the data should share a common interpretation of the data, i.e. a shared semantics. Level three, the application level, describes the systems used by the business. The integration goal is *interoperability*, which is the ability of one

software application to access/use data generated by another software system. Level four, the work process level, describes the tasks and the manner and order in which they are conducted in order to produce an output. The problem of task dependencies occurs at this level and the integration issue is called *coordination*. *Coordination* has been defined as the “management of the dependencies that arise between business tasks”(Malone and Crowston 1994). Finally, level five, the level of organizational design, addresses the way that the three key elements of business strategy, organizational design strategy and information systems strategy must all be aligned with one another. A change in any of these elements requires an adjustment in the others. Thus *alignment* is the integration task at this level of analysis (Butler and Fitzgerald 1999; Henderson and Venkatraman 1993; Sabherwal and Kirs 1994).

This framework is intended to unite different perspectives of enterprise integration. For example, middleware approaches focus on interoperability at the application level, database approaches on the data level, and cross-functional teams at the process level. Each integration type will allow for constructions of measures of enterprise integration. Enterprise integration within a single company implies alignment within and between the different levels into a cohesive enterprise system. Inter-enterprise integration can occur at any level. The framework is, of course, preliminary and incomplete. The definitions for both the levels and the integration types need further formalization and development. Relationships between the levels remain undefined. The entire framework needs to be validated within an industry setting. Regardless of these short-comings the framework is an important first step towards establishing a language of integration since the different types of integration are clearly distinguished from one another.

3.1 Measure of Agility as the Complexity of the Enterprise System

Systems engineering involves the engineering of complex systems, where systems is a group or combination of interrelated, interdependent, or interacting elements that form a collective entity. Elements may include physical, behavioral, or symbolic entities. Elements may interact physically, mathematically, and/or by exchange of information. Furthermore, complex systems are systems whose perceived complicated behaviors can be attributed to one or more of the following characteristics: large numbers of elements, large numbers of relationships among elements, nonlinear and discontinuous relationships, and uncertain characteristics of elements and relationships (Arteta and Giachetti 2003).

Agility is the ability of an organization to adapt to change and also to seize opportunities that become available due to change. While there has been much work and discussion of what agility is and how firms can become agile there is little work at measuring the agility of a firm. Measurement is necessary for the strategic planning of determining how much agility an organization currently possesses, determining how much is needed, and then for assessing the gap and formulating a strategy for closing any perceived weaknesses. The measurement of agility as defined is difficult to measure since it must be measured in the context of a change. Consequently, most current agility measurement approaches are backwards looking. A different and novel approach is to use complexity as a surrogate measure for agility. The hypothesis supporting this substitution is that a less complex enterprise in terms of systems and processes is easier to change and consequently more agile. To test this idea a model and measurement approach for measuring complexity is presented. The model uses Petri Nets to find the state space probabilities needed for the complexity measure. The contribution of this research is the quantification of complexity at the business process level and description of a method for conducting this measure.

4. Conclusion

Enterprise Engineering is the discipline that embodies the knowledge, principles and practices relating to the analysis, design, implementation and operation of an enterprise. This discipline builds upon several reference disciplines in science, engineering, and humanities, such as Industrial Engineering, Systems Engineering, Information Systems, Business Process Reengineering, and Organizational Design. The

proposed framework views the enterprise at five levels which are network, data, application, process, and organization. Corresponding to each level is a specific integration type defined as connectivity, data sharing, interoperability, coordination, and alignment respectively. Using this framework we described how different projects at FIU fit together. One of these projects has been conducted to measure the coordination load, which is defined as the difficulty of coordinating business processes using a model that will be empirically tested through a survey and laboratory experiments. Other project that is under development is the contingency-based model of integration requirements. In addition, we are also working on a project that models the relationship between integration and complexity.

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