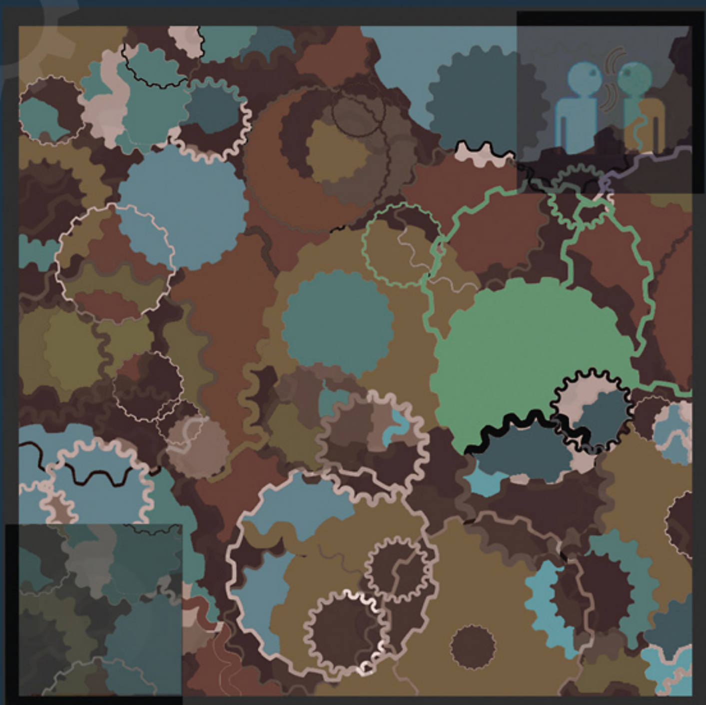
Design of Enterprise Systems

Theory, Architecture, and Methods



Ronald E. Giachetti

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Preface

Design is the defining characteristic of engineering. Each engineering discipline is strongly associated with the artifact it designs. In mechanical, electrical, and civil engineering the artifact is a physical, technological system. This is not so for engineers who design enterprise systems. What distinguishes the design of enterprise systems from other designed systems is twofold: first the design artifact – the enterprise system – is not tangible, and second, enterprise systems include humans as part of the artifact, not as users of the artifact.

The term "enterprise system" has taken on a narrow meaning of only the information system an organization uses. Research and project experience has taught us that to design a good enterprise system, we need to adopt a much broader understanding of enterprise systems. The greater view of enterprise systems is inclusive of the processes the system supports, the people who work in the system, and the information content of the system. Hereafter, I shall use the term *enterprise systems* to refer to not just the information system, but to the enterprise itself. This use of the term encompasses companies (both manufacturing and service), not-for-profits, and government organizations.[1] Adopting this view encourages us to analyze the integrated system and focus on the relationships between the components that can lead to better system designs, and consequently, project success.

In many ways, the abstract characteristics of enterprises make their design much more challenging than the design of physical objects. First, the fact that enterprises have both physical and abstract aspects makes the representation of the system difficult. There are countless ways to model a process, which is only a single part of an enterprise. In fact, there are countless ways to even define what a process is, highlighting the abstract nature of dealing with enterprise systems. Second, enterprises include a human element, and we have as yet found equations that model humans as accurately as we can model stress/strain, mechanical loads, or the flow of electrons. While civil, mechanical, and electrical engineers can base design decisions on analysis that draws from physics, chemistry, and other basic sciences, the enterprise engineer must also include sociology and psychology to understand the human element. Moreover, enterprise design does not occur at a single point in time like the design of most systems. Instead, enterprises evolve over time and are constantly changing, or are constantly *being designed*.

In practice, many different people with backgrounds in many different disciplines contribute to the design of an enterprise. It is not only engineers but people from management, organizational theory, accounting, finance, business process design, psychology, and sociology that all study, analyze, or design parts of the enterprise system. Anybody that makes decisions to change the current enterprise to achieve some preferred structure or performance is a designer. What is problematic is that the knowledge of enterprise design is fragmented. Each specialty is important for the design of enterprises, but what is lacking is the holistic and systems-wide perspective to integrate the specialized knowledge of separate aspects of the enterprise to achieve a globally optimized enterprise. What is really needed is a new term, *enterprise engineering* to describe the discipline that focuses on the design of enterprise systems. Enterprise engineers need to have knowledge in a broad area of enterprise systems. Enterprise engineers will not have the same depth of knowledge in each

[1] The word "organization" also fits this criteria, but we reserve this word to later specify the organizational structure of an enterprise.

sub-specialty as their counterparts in each contributing field. What enterprise engineers specialize in is integration: the process of making subsystems work together harmoniously in a way that optimizes the performance of the entire enterprise. The integration of many disparate systems, processes, people, and resources is specialist knowledge – the knowledge of the enterprise engineer.

The purpose of this book is to describe an enterprise engineering methodology. Because enterprise systems are exceedingly complex, encompassing many independent domains of study, students must first be taught how to think about enterprise systems. This book takes a system-theoretical perspective of the enterprise, and describes a systematic approach, called an enterprise design method to design the enterprise. The design method demonstrates the principles, models, methods, and tools needed to design enterprise systems. The book details the enterprise engineering process from initial conceptualization of an enterprise to its final design.

Intended Audience

The book is aimed at three groups: engineering students, business students, and working professionals. My intention is that this book fills a need for greater design content in engineering curricula by describing how to design enterprise systems. Inclusion of design is also critical for business students, since they should realize the importance their decisions may have on the long-term design of the enterprises they work with. Forrester[2] uses the analogy of an airplane to explain the difference between enterprise design and enterprise operation. There are two groups of people: those who design the airplane and those, the pilots, who fly the airplane. The pilot's success depends on the airplane designer to create a good airplane. Most all textbooks in related areas such as operations management, manufacturing systems, etc. are aimed toward the operator or manager of the enterprise, not the designer. Somebody must design an enterprise system; so there is a need to collect the theory, models, tools, and methods to design enterprise systems in a single book.

Organization

To present all the topics needed to analyze and design an enterprise is a tremendous undertaking; what I have decided to focus on is the life cycle of an enterprise from initial conceptualization to final design. This includes the design models, tools, and methodology to design an enterprise. The book uses an enterprise reference architecture that contains three views: process, organization, and information. The enterprise architecture is used to provide a model to understand how the parts of the enterprise fit together. The enterprise architecture is also used to organize the last four parts of the book.

The book is organized into six parts as follows:

- Part I establishes the foundation for enterprise engineering and the remainder of the book. Chapter 1 describes the history of thought leading up to enterprise engineering. It describes the knowledge required to do enterprise engineering, a classification of enterprises, and the types of enterprise engineering projects. Chapter 2 describes systems

[2]Forrester, J.W., Designing the Future, Universidad de Sevilla, Sevilla, Spain, December 15, 1998.

theory and how it can be used to understand, analyze, and design enterprises. Chapter 3 describes modeling concepts because building models is required for the analysis and design of enterprises. Chapter 4 reviews engineering design theory and the enterprise design methodologies. Chapter 5 reviews enterprise architectures. Chapter 6 presents the enterprise design methodology that is used in this book.

- Part II contains three chapters describing the preliminaries and initiation of an enterprise project. Chapter 7 describes strategy as a guide for defining how the enterprise should be designed. Chapter 8 discusses problem formulation and requirements engineering. Chapter 9 describes how to generate and evaluate alternatives.
- Part III focuses on the process view of the enterprise. Chapter 10 describes how to model processes. Chapter 11 reviews queueing theory, which is used to analyze processes. Chapter 12 describes approaches to analyze and design processes.
- Part IV focuses on the information view. Chapter 13 describes how to model the information structure of the enterprise. Chapter 14 describes a design methodology, SQL, and normalization.
- Part V focuses on the organization view. Chapter 15 discusses organizational theory and describes an approach to organizational design.
- Part VI describes the integration of the three views of process, organization, and information. Chapter 16 defines five types of enterprise integration, the technical architecture of systems, and integration technologies. Chapter 17 describes techniques for integrating the three enterprise views. It summarizes the design methodology by showing how all the independent subsystems come together.

Website

The author maintains a Website at http://web.eng.fiu.edu/Ronald/ that contains:

- Powerpoint slides for each chapter.
- Templates to support enterprise engineering activities, including: Project Charter, Business Case, Cost-Benefit Analysis, Risk Management Assessment, Problem Analysis, Requirements Analysis, Alternative Matrix, Evaluation Matrix, Process Design, Information Design, Organization Design, Interface List, and more.
- Project case studies that can be assigned to students as semester-long projects to accompany the text.
- Quiz questions for each chapter.
- Business Process Analyzer software for download.

Book Features

The book has the following special features:

- Focus on doing enterprise engineering – The book encourages the reader to apply the enterprise system design concepts and techniques. For each major technique, the book provides examples and explains best practices. The review questions and exercises, and accompanying projects all emphasize the practice of enterprise engineering.
- Business Process Analyzer – A spreadsheet and VBA implementation of multi-class queueing networks using the parameter-decomposition method for GI/G/n queues that allows students to model a business process and estimate the performance measures of cycle time, waiting time, and resource utilization.
- Coverage of information modeling – The book using entity-relationship models and shows how to create the models, normalize them, and write SQL.
- A project-based approach – The book uses the enterprise system design method that consists of seven phases. An accompanying project lets the reader understand the inputs, activities, and outputs of each life-cycle phase.
- Coverage of architecture – The enterprise architecture provides a high-level design of the enterprise and guides all other system projects.
- Chapter on integration – A chapter describes how to integrate the three architectural views with each other and with enterprise technologies.
- Instructor resources – Available to instructors on the Website are an accompanying project book, PowerPoint files for each chapter, quizzes, and exam questions.
- Student resources – Available to students on the Website are accompanying templates, checklists, forms, and models to support the enterprise engineering process.

Acknowledgments

I started collecting information and writing this book in 2005. Since that time I have had useful discussions, suggestions, and outright help from many different people. I would like to acknowledge my colleagues at FIU and the many students who took my courses (at FIU in Miami; at Tecnolgico de Monterrey (ITESM), Chihuahua, Mexico; at Universidad del Norte in Barranquilla, Colombia; at the University of Technology, Kingston, Jamaica; and the Peru Catholic University, Lima, Peru), and did projects with me, or did their dissertation work with me. I would like to specifically acknowledge the help of Lixiang Jiang who worked with me to develop the queueing network approach to analyzing business processes; Duane Truex a colleague and friend from the business school who introduced me to a new way of viewing methods and collaborated on the ERP short course for the U.S. Air Force; Ching-Sheng Chen who I frequently discussed enterprise systems theory with; Mario Kim for helping to design the cover artwork and drawing the abstraction of the horses for me; and to the Ph.D. students I supervised who helped advance my research: Ramakrishnan Sundaram, Oscar Sáenz, Jose Rojas, Rene Amaya, Heriberto Garcia, Alba Nuñez, Bertha Arteta, Maria Paula Hernandez, Chris Ellis, Giacomo Boria, and Sergio Hernández.

Author Biography

Ronald E. Giachetti, Ph.D., is an Associate Professor of Engineering Management at Florida International University (FIU) in Miami, Florida. Prior to joining FIU in 1998, he worked at the National Institute of Standards and Technology in Gaithersburg, Maryland. He conducts research in enterprise systems, operations research, and information systems. He has completed projects for government agencies including the National Science Foundation (NSF), U.S. Air Force, and National Aeronautics and Space Administration (NASA). For the U.S. Air Force at Wright Patterson he and a colleague developed a short course on Enterprise Resource Planning (ERP) Project Management. At NASA he worked with the Ames Research Laboratory and developed an enterprise integration methodology to help them address their information integration challenges. He has also completed projects with industry including Carnival Cruise Lines, Royal Caribbean Cruise Lines, Americatel, Baptist Healthcare and KoolSmiles Dentistry. These industry projects focused on business process improvement. He has published over 50 journal articles, book chapters, and conference papers on this work. At FIU he teaches courses in enterprise systems and operations research to both undergraduate and graduate students. He has received the IIE Teacher of the Year award three times at FIU. He teaches in the graduate Engineering Management program on campus and through FIU's Global Programs Office. He has taught graduate students in Mexico, Jamaica, Peru, and Colombia. He has a Ph.D. in Industrial Engineering from North Carolina State University, an MS in Manufacturing Engineering from Polytechnic University, and a BS in Mechanical Engineering from Rensselaer Polytechnic Institute.

Part I

Enterprise Engineering

1

Enterprise Engineering

"The world hates change, yet it is the only thing that has brought progress." – Charles F. Kettering (1876-1958), inventor and head of General Motors Research, 1920-1947.

This chapter introduces enterprise engineering as the discipline concerned with the design of enterprises. It provides an overview of what enterprise engineering entails and how enterprise engineering projects are initiated and managed. This chapter reviews the historical background, intellectual development, and industry trends that have led to a need for enterprise engineering. After completing this chapter, you should be able to:

- Define enterprise engineering and explain why it can be considered a separate discipline.
- Categorize enterprises according to their type.
- Describe how enterprise engineering projects are conducted.
- Discuss the intellectual developments that have contributed to modern thought on enterprise systems.
- Explain how enterprise engineering is related to systems engineering.
- Describe the requisite skills and knowledge for enterprise engineering.
- Assess an enterprise environment and how it affects the enterprise.

1.1 Definition of Enterprise Engineering

Enterprise Engineering is defined as the body of knowledge, principles, and practices to design an enterprise. The key of the definition is *to design*, which is considered the characteristic, defining activity of engineering. Moreover, an enterprise is not designed just once, but an enterprise is, to varying degrees, redesigned many times until its eventual retirement. Enterprise engineering is a subdiscipline of systems engineering in that it addresses the entire life-cycle of an enterprise.

Enterprises have of course existed for millennia. The word might be new, certainly the technology employed by enterprises is new, but the organization of man and machines in pursuit of some common goal is not new. So, if enterprises have always existed, how have they been designed? To a large extent, in the past, the enterprise was not viewed as a whole system that could be rationally designed. More likely, parts or subsystems of the enterprise were designed in isolation without a holistic perspective of how the parts would work in the entire system. Enterprises would come into being and change not as a result of a conscious, purposeful design effort, but due to ad hoc, sometimes short-term decisions made individually by many different people. Many businesses that had grown quickly paid little

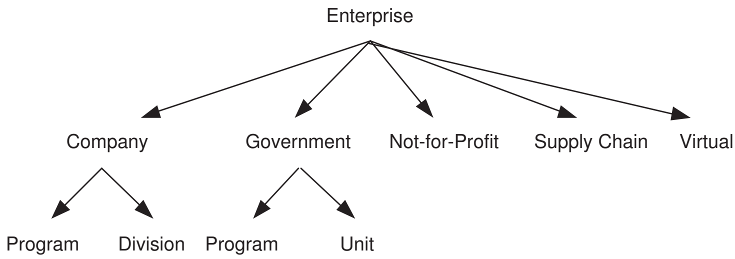

FIGURE 1.1
Enterprise systems.

attention to the design of their processes and systems. Porter [25] cites a study by Ernst and Young that found in many companies the key business processes were designed long before there was information technology. Even though these companies had new IT systems, they continued to follow the paper-based business processes but with IT. What this study and other observations indicate is that for many enterprises their current structure does not reflect the results of a rationale design, but the result of a multitude of small changes made over time without consideration of the overall enterprise.

1.1.1 Enterprise Systems

An *enterprise* is a complex, socio-technical system that comprises interdependent resources of people, information, and technology that must interact with each other and their environment in support of a common mission.[1] As a system, it is the interactions that are important to the enterprise behavior. Interactions include such activities as coordination of functions, sharing of information, and allocation of resources. The enterprise is a socio-technical system in that it involves people and technology, it is an open system in that it interacts with its environment, and it is purposeful in that it has goals that it works towards accomplishing.

We use the term enterprise because it encompasses all types of organizations: companies, government, not-for-profit, supply chains, virtual enterprises, as well as parts of a company such as division or program. The term organization is not used because later we use it to describe one of the views of the enterprise. Figure 1.1 shows the classification of different types of enterprises. The enterprise types are:

- Companies defined as commercial enterprises that pursue a market position to return long-term profits to the business owners. Frequently when we talk about enterprises we are referring to companies. A large company will have many semi-independent business units that are also enterprises in their own right.
  - A division is a semi-independent business unit that usually focuses on a single market.
  - A program is a temporary, but long-duration collection of activities to produce a particular product, system, or service. The program enterprise usually will have a single business process for developing and delivering the project, and it will usually encompass the entire life-cycle of the product it produces. Program enterprises

[1] In the software and business literature, the term enterprise system frequently has a more narrow definition of a large, enterprise-wide information system such as ERP.

are common in the defense industry (e.g., the B1-B program) or the automotive industry (e.g., Chrysler's LH platform).

- Government organizations at all levels (national, state or region, city or town) are enterprises. Government enterprises pursue goals to provide a service or product to citizens. Government organizations can be subdivided into programs or units. A program is defined the same as in businesses. Governments are also subdivided into units, and each unit is an enterprise in its own right.

- Not-for-profit organizations are charities, funds, and volunteer organizations. Non-profit enterprises pursue goals to improve society.

- Supply chain, which are the collaboration of multiple, separate companies involved in the development and delivery of a product or service.

- Virtual enterprises defined as enterprises that are quickly created to exploit a market opportunity and then once the opportunity passes the enterprise dissolves. Hollywood makes use of temporary enterprises to create films [13]. It could also be a temporary, not-for-profit enterprise such as Hurricane Relief for Haiti, or a temporary government enterprise such as the U.S. Federal Government's $700 billion bailout plan for banks, which will require a small organization to execute and then disband once the money is distributed.

These enterprises have the following in common:

- All enterprises are man-made systems, where a system is an integrated collection of components (people and technology).

- All enterprises use resources of people, material, machines, information, and knowledge.

- All enterprises produce a product, provide a service, or do both.

- All enterprises have customers who derive value from the product or service.

- All enterprises have a goal: in for-profit enterprises the goal is profitability and growth. Other enterprise types may have different goals.

- All enterprises interact with their environment. They obtain raw materials, labor, and other resources from their environment, they compete with other enterprises, they collaborate with other enterprises (e.g., in supply chains), and they are subject to changes in the political, social, economic, and technical aspects of their environment.

1.1.2 Enterprise Engineer

The definition of enterprise engineering casts the enterprise as a product. If an enterprise is a product, then it must have a designer. It is unusual for a single person to design an enterprise, instead it usually involves many people from different disciplines during all phases of the design project. We shall call this group the enterprise engineering team. In addition to the enterprise design that results from a project, enterprise design is an ongoing, incremental activity. All managers are constantly making enterprise design decisions. Sometimes managers consciously consider their decision's impact on the long-term design of the enterprise; they consider whether the current decision will set a precedent that will become established policy in the enterprise. Other times, decisions are made without forethought of how they impact enterprise design. Consequently, managers are also enterprise designers because the decisions they make change the enterprise. A central argument of this book is that enterprise design should be a conscious, purposeful endeavor, and managers should regularly review their systems from multiple perspectives to ascertain whether they are meeting enterprise needs.

Now that we established that enterprise design is done primarily on projects, we need to describe the job titles of some of the people who would be part of the enterprise design team. These are:

- *Business Systems Analyst* is a person who identifies and analyzes business problems, and generates system requirements. The Business Systems Analyst is a person who needs to be conversant in both the business domain language (e.g., accounting) as well as understand the technology that might be used in that domain. There are similar job titles of Business Analyst, System Analyst, and Process Analyst for people with similar job descriptions.
- *Enterprise Architect* is a person who develops a holistic view of the enterprise's strategy, processes, information, and organizational structure – usually delivered as the enterprise architecture.
- *System Architect* is a person who creates the high-level design of a technical system. Here, system means a subsystem of the enterprise such as an ERP system, or the accounting system. The difference in scope is what differentiates a system architect from an enterprise architect. If the system in question is software, then the title might be software architect.
- *Project Manager* is the person responsible for accomplishing all project objectives. The project manager would play a role in identifying all team members, planning the project, supervise team members, monitor project progress, and is responsible for all project deliverables.
- *System Designer* is the person who designs one or more parts of the system. The system designer is a technical person who generates the specifications for how the system will work.
- *Change Manager* is the person responsible for the change management plan. All new enterprise systems involve change, and the change manager plans the change, supervises the change management sub-team, monitors the progress of the change, and is responsible for the successful execution of the change management plan.
- *System Engineer* is a technical person who is involved with the overall process of defining, developing, operating, maintaining, and ultimately replacing quality systems. System engineers concentrate on the integration of all the system components and the entire system life-cycle.[2] A system engineer also has broad knowledge of all the other disciplines involved in the project. The depth of this knowledge is described as being two questions deep [23]: First, what technology is relevant to the problem at hand? and second, What is the telephone number of an engineer who knows this technology in depth?
- *Application Developer* is a technical person who builds new software systems. There are many variations depending on the technology including: web application developer, Java developer, ERP developer, etc.

The list of job titles and descriptions conveys the breadth of the skills required for an enterprise engineering project.

[2] INCOSE http://www.incose.org/educationcareers/careersinsystemeng.aspx

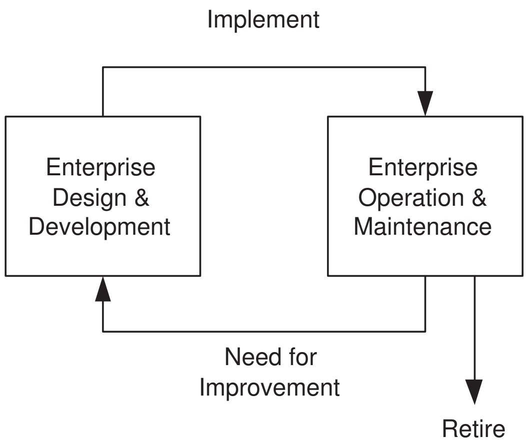

FIGURE 1.2
Relationship between enterprise development and operation.

1.1.3 Enterprise Life-Cycle

The concept of a life-cycle is central to systems engineering. Whether the system is a satellite, power plant, mass transit, or any other large and complex system it has a life-cycle. The enterprise *life-cycle* describes the history of the enterprise from the initial concept of a business in the mind of an entrepreneur, through a series of phases as the enterprise grows, until the business venture ends. The enterprise life-cycle consists of three general, distinct stages: development, deployment, and operation. Development covers the engineering phases to create an enterprise system, deployment is the change management process to implement the enterprise system, and operation is the management of the enterprise system and its continuous improvement. These three stages are described by more precise phases, where a *phase* is a step in the life-cycle that delineates the project's progress. How a life-cycle is broken up into phases differs with each methodology, but we can identify the typical enterprise life-cycle phases as:

1. System identification – The system boundaries, purpose, and project scope are defined.
2. Analysis – The system problems are analyzed; requirements are generated.
3. Design – The system design is generated.
4. Construction – The system is built.
5. Implementation – The system is implemented and deployed into its environment.
6. Operation and Maintenance – The system is operated and maintained.
7. Decommission– The system is retired.

Phases 1 through 4 are part of the enterprise development methodology. These are the phases done during an enterprise engineering project to develop a new enterprise or enterprise subsystem. Phase 5 is the deployment phase when the enterprise is implemented and deployed into its environment. Phase 6 is the operation of the enterprise until it is decommissioned in phase 7. Figure 1.2 shows that an enterprise might cycle through many development projects before being decommissioned.

1.1.4 Enterprise Design Method

To design an enterprise is a complex undertaking involving a large group of people over a long period of time. In order to be successful, the project team members need to work together in an effective and efficient manner. To accomplish this, we view enterprise design as a problem. The problem can be posed as:

> Given a project goal, determine the problem scope and problems; analyze them and generate requirements; generate alternatives, evaluate them, and choose the best alternative; design the enterprise system; implement the design; and maintain the design with periodic updates to improve the enterprise.

To solve such complex problems engineers use methodologies. A methodology is a staged problem-solving approach. A general problem-solving methodology is:

1. Scope the problem.
2. Design the solution.
3. Evaluate the solution.
4. Satisfactory? – If not, then repeat.

The goal of an enterprise design methodology is to specify and develop a “best” system solution that will demonstrably satisfy the requirements of all enterprise stakeholders. A *stakeholder* is any person who can affect or is affected by the achievements of the enterprise’s goal [12]. As social systems, enterprises tend to have many stakeholders. When there are many stakeholders, just to define what the enterprise should be doing and what its goals are is a difficult task. One goal of an enterprise methodology is to provide a systematic approach to understanding all the stakeholder perspectives, understanding the problem situations facing the enterprise, and determining a strategy for meeting the stakeholder needs. This is done in phases 1 and 2 of the problem-solving methodology presented above.

In addition to understanding the design problem, a methodology needs to guide the team on how to generate solutions (or designs) to satisfy the requirements. This is done in phase 3 of the problem-solving methodology.

Once a design is proposed, there needs to be a way to evaluate how good the design is. Again, a methodology must include activities, techniques, and tools to help the team evaluate the feasibility, economics, and merits of proposed design solutions. This is done during phase 4 to test the solutions.

The enterprise design methodology is iterative, and it takes several iterations of understanding, analyzing, designing, and evaluating before arriving at a final enterprise design. Once a design is selected, the methodology needs to help the team construct the system, which involves a combination of building new systems, acquiring systems, training people, generating documentation, and other activities needed to create the enterprise system. Implementation is a matter of going live with the system; change management is the critical activity here, and frequently the determinant of overall project success.

The enterprise design methodology supports projects of varying scopes. Enterprises must interact with other enterprises. For example, businesses are organized into supply chains, and it is recognized that supply chain interactions and performance are important to each individual supply chain member. An enterprise design method supports both the design of an enterprise subsystem, an entire enterprise, as well as the design of large, complex supply chains. Later in Chapter 4 we discuss at length various enterprise design methodologies.

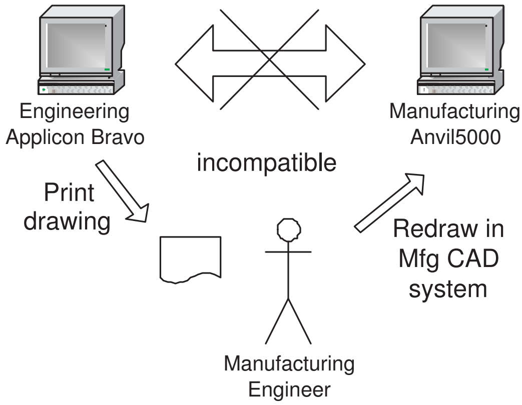

FIGURE 1.3
Result of poor acquisition decisions when there is no enterprise architecture.

1.1.5 Enterprise Architecture

Seldom is the entire enterprise designed in a single project. More likely, there are many smaller projects that design one or more parts of the overall enterprise. For this reason, we say the design of an enterprise never really ends. Enterprises need to evolve and change over their life-cycle. The problem becomes how do you ensure all the separate design projects will lead to some desired vision of the enterprise? It has occurred more than once where one part of an enterprise is designed only to find out it does not work well with other parts of the enterprise. For example, the author's first industry job was in an aerospace company. At the time the manufacturing division was moving aggressively into computer-integrated manufacturing. They acquired a computer-aided design (CAD) system called Anvil5000 based on a wire-frame modeling technique to support their operations. The CAD system let them define work instructions and generate numerical control programs for the machines. Soon after, the engineering division acquired a new CAD system from Schlumberger called Bravo. This CAD system had good solid modeling capabilities that supported various types of engineering analysis. The two CAD systems were incompatible and it soon became apparent the types of problems that would occur. Designs developed in Bravo by engineering would have to be completely redrawn in Anvil5000, resulting in a wasted duplication of efforts (see Figure 1.3). The result was problems of maintaining consistency between design documentation and the manufacturing documentation. What had happened is that each division developed their systems without consideration of how it would work in the overall enterprise. Eventually, it was decided that manufacturing would switch over to Bravo, essentially abandoning its earlier investments in equipment, training, and process changes associated with the purchase of Anvil5000.

To avoid these types of problems, the enterprise needs to provide an overall enterprise design to guide all other projects. An enterprise architecture fulfills this role. An *enterprise architecture* is a high-level design of the enterprise. The enterprise architecture specifies an enterprise-wide view of the processes, information, and organization of the enterprise and how the three views are integrated. Whenever, a small enterprise project is embarked on, the project deliverables should conform to the enterprise architecture. In this way, the enterprise can ensure that all these projects contribute towards enterprise-wide improvement and attainment of the enterprise goals. Returning to the aforementioned aerospace company, if they had an enterprise architecture, it would have described the needed information flow, contained principles for interoperability, and provided a holistic plan that would have highlighted the impending integration problems of the CAD selection decisions.

In today's rapidly changing world, having an enterprise architecture may be insufficient to guide enterprise design. Consequently, an important design goal is to design the enterprise so that it can easily change to meet future requirements. This leads to the many "-ilities" to describe various means of change including flexibility, agility, and scalability. The idea is that an enterprise is designed so that it can not only react swiftly to unexpected changes in its environment, but also seize the opportunities offered by change for its competitive advantage [13, 3]. Enterprises that can change themselves (redesign) to adapt to unforeseen changes are more likely to succeed.

1.1.6 Enterprise Engineering Projects

It is obvious that enterprise engineering can be applied to new enterprises. A small start-up business requires a complete design of its systems. Less clear is how to apply enterprise engineering to existing enterprises. Existing enterprises are continuously being changed via either projects or continuous improvement programs. So, while for many enterprise engineers it is unlikely they will encounter in their entire career a situation in which they can design a complete enterprise from a clean slate, the redesign of existing enterprise subsystems is a very common project. Typical enterprise design projects are:

1. Strategy-initiated project. This project type stems from the strategic plans of the organization. A project performed by a charity organization in Fort Lauderdale, Florida provides an example of an enterprise design project that was done to implement a strategic vision. The charity provides food for the poor, elderly citizens of the city. A question was asked of them if they provide fresh produce. The answer was that they currently did not have the capability, but provision of fresh produce was part of their strategic vision. To add this capacity, they were developing a project plan to develop the processes for acquiring, for cold storage, and for distribution of fresh produce. This is enterprise design. The charity needs to develop the business processes, the organization, and all the subsystems needed to have this capability.
2. Subsystem design. As enterprises grow, contract, or change there is a need to design or redesign enterprise subsystems. These subsystems include:
    (a) Subsystems defined by view: Analyze and design a subsystem that involves one view of the enterprise, such as the information, process, or organizational view.
    (b) Subsystems defined by process: Analyze and design an end-to-end business process. For example, the order fulfillment process.
    (c) Subsystems defined by organizational unit: Analyze and design a single organizational unit of the enterprise. This can be a division, department, or other unit. For example, a company that is entering the Asian market for the first time might need to design the entire Asian division including the organization, information systems, and processes.
3. Reengineering or other large-scale transformation projects. Business Process Reengineering (BPR), or sometimes just reengineering, describes a project to essentially replace an existing enterprise system with a new enterprise system. What distinguishes BPR from other projects is the project team purposefully looks for completely different ways to design the system in order to achieve dramatic improvements in system performance. This is different than many projects

that seek incremental improvement by making small changes to the existing system. During the 1990s, BPR was popularized by Hammer and Champy [16] – it is still practiced today, but not with the zeal exhibited in the 1990s.

4. Enterprise information system. An enterprise information system is a large, enterprise-wide information system to partially automate one or more business functions. This category includes Enterprise Resource Planning (ERP) systems, Supply Chain Management (SCM) systems, Data Warehouses, Customer Relationship Management (CRM) systems, and e-commerce systems. These enterprise information systems represent not only technology, but also a change in business processes, information structure and flow, and organizational structure. For this reason, they are not just a technology project but an enterprise engineering project.
5. Continuous improvement. Most companies institute some type of continuous improvement programs (six sigma, total quality management (TQM), or kaizen). The small decisions and changes made in continuous improvement are design changes to the organization and consequently should be guided by enterprise architectures that describe what the company wants to look like.
6. Supply chain project. A supply chain describes the relationships between companies that trade with each other. To set up a supply chain relationship requires a project that impacts the companies' information systems, processes, and organization. It is therefore an enterprise engineering project.

1.2 Need for Enterprise Engineering

Enterprises have long been studied by researchers in the management sciences, engineering, social sciences, and information sciences. Typically, each discipline would study a single subsystem of the enterprise or study the enterprise from only a single perspective. For example, industrial engineers traditionally consider only the production subsystem. Moreover, they predominantly emphasize efficient operations of the production subsystems. Organizational scientists mostly investigate the structure of the organization. Behavioral scientists study the decision-making in the enterprise or how the interaction between workers, management policies, and the work environment affect productivity. What many researchers and industry leaders now see is there is a lack of an overall, all-encompassing view of the enterprise. Our knowledge is compartmentalized in separate disciplines. What is needed is an enterprise-wide view to understand the problems facing enterprises as a whole and not separately.

Unfortunately, the nature of our university system encourages researchers and students to stay narrowly focused in their specialty. The reason is threefold. First, it is easier for researchers to make significant contributions in narrowly defined domains than in a larger, broader context. Second, the amount of knowledge has increased so much that it is becoming difficult to master more than a few topics. Third, most universities are structured such that each discipline is a different department, physically located together, with a curriculum mostly taught within the department. This structure limits cross-disciplinary learning and reinforces the developed specialization of the students.

The problem is that enterprises have become more complex, the environment they operate in changes quickly, and the competition they face has increased. For this reason, many industry leaders, researchers, and policymakers have raised the call to develop enterprise engineering as a discipline (see Sáenz et al. [30]). The term used is not necessarily enterprise engineering. For example, Towill [34] says there is a need for what he calls a "business systems engineer" who uses a systematic approach to design new business processes and to redesign existing business processes to maximize customer value and the business's performance. Likewise, Leung et al. [18] at IBM argue for the need of business process engineers. Rouse [28] makes similar arguments that industrial engineering needs to expand their focus to the entire business enterprise including external entities such as suppliers, vendors, and distributors. Liles [19] argues for enterprise engineers who know "how to design and improve all elements associated with the total enterprise through the use of engineering and analysis methods and tools to more effectively achieve its [the enterprise's] goals and objectives."

There are several calls from outside of the engineering discipline for the need of enterprise engineering. Davenport and Short [11] describe the need of engineers who analyze and design business processes and know how to apply IT to improve them. Also, the same author later argues how commercially available information systems, often called enterprise systems, are just that, large information systems [10]. These systems often lack an enterprise model or are not well implemented because of the lack of enterprise engineering principles. Consequently, there is a need for a discipline that studies the large picture of the entire enterprise.

Martin [20] specifically states the need for enterprise engineering and defines enterprise engineering as consisting of a series of change management methods. In this view, enterprise engineering is needed to constantly change the enterprise so that it can meet new challenges and prosper. Alter [1] argues instead of enterprise information systems we need to conceptualize them as work systems. He remarks most system implementation failures are not technological in nature but due to not designing the information system for the enterprise. Again, he is arguing against the technical focus that dominates the implementation of large information systems, and instead the need to have multiple perspectives that see these systems are part of the larger enterprise.

These authors recognize a need to transition from a situation in which enterprises are evolved in an ad hoc fashion to a systematic, or an engineering approach, to the design of enterprises. To accomplish this, an enterprise engineering discipline needs three foundations:

1. Enterprise integration knowledge.
2. Enterprise architecture.
3. Enterprise methodology.

The first foundation, enterprise integration knowledge, describes the ways that the parts of the enterprise can be coordinated and integrated so that they work together as a harmonious whole. This knowledge is not part of the sub-disciplines of enterprise engineering. The second foundation, enterprise architecture, is needed to provide a unifying view of the enterprise design. The third foundation, enterprise methodology, describes the formal engineering approach to design an enterprise. Included in the methodology are the methods, techniques, and tools for each phase of the enterprise design process.

What will an enterprise engineering discipline deliver? For one thing, it will provide the holistic view required to design an enterprise. While the many subsets of what is defined as enterprise engineering is not new, the integrated knowledge and focus on enterprise design is novel. Both the enterprise architecture and the methodology will lead to better enterprise designs and more successful enterprise engineering projects. Nowadays, when enterprises are purposefully designed they are usually done based on experience and judgment. Clearly some designs are better than others; however, except for specific cases there is a lack of rationalization justifying a particular enterprise design. The enterprise engineering knowledge will provide the rationale to answer why and how enterprises are designed.

1.2.1 Enterprise Engineering Compared to Systems Engineering

Enterprise engineering is closely related to systems engineering. The International Council on Systems Engineering (INCOSE) defines systems engineering as, "an interdisciplinary approach and means to enable the realization of successful systems." Systems engineering entails the entire life-cycle of a product from determining customer needs, documenting the requirements, designing the system, testing, and then deployment. Systems engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

Traditional systems engineering focuses on technical systems like airplanes, satellites, or it deals with construction projects like dams and nuclear power plants (see for example, pp. 38-39 in [6] as well as [31]). The systems engineering approach is to decompose the complicated design problem into smaller sub-problems that when solved can be integrated together seamlessly to arrive at a solution to the original system design problem. Systems engineering addresses the problems of how to identify the system requirements, how to manage large-scale engineering projects with many stakeholders, and how to design complex systems.

Enterprise engineering is systems engineering but limited to the design of the enterprise, a socio-technical system. The basic ideas of systems engineering carry over to this domain: the life-cycle phases, development methodology, and tools. But we must adapt some systems engineering concepts, discard some, and add new ones. Most of the changes are due to the following two main differences between enterprises and technical systems:

- The human in the enterprise is a significant, distinguishing characteristic of enterprise systems [35].
- Enterprise design is a continuous process, not limited to single projects.

A consequence of the human component of the enterprise is that enterprise engineers need to consider how the people work in the organization. Enterprise engineers require background knowledge in the organizational sciences, sociology, and psychology. The fact that enterprises are constantly evolved makes it different than other systems that are designed and built as part of a single project. As a result, enterprise architecture plays an important role in aligning all the small developments in the enterprise so that they all contribute to the overall enterprise design goals.

In addition to systems engineering, we believe the root disciplines include industrial engineering, systems engineering, organization sciences, psychology, sociology, information sciences, and the management sciences. The study of enterprise engineering involves understanding this vast domain knowledge and how it can be applied toward the design of enterprises [19].

1.2.2 Skills and Knowledge of Enterprise Engineers

We say the design of an enterprise is done by an enterprise engineer. Engineering is a discipline with a body of knowledge that can be taught. The knowledge and skills required to do enterprise engineering are as follows:

1. Systems thinking defined as the ability to visualize enterprises as systems and use systems theory in the understanding, analysis, and design of enterprises.
2. Domain knowledge of the business, whether manufacturing, healthcare, transportation, energy, or any other domain.

TABLE 1.1
Twenty Greatest Engineering Achievements

1. Electrification	11. Highways
2. Automobile	12. Spacecraft
3. Airplane	13. Internet
4. Water supply and distribution	14. Imaging
5. Electronics	15. Household appliances
6. Radio and television	16. Health technologies
7. Agricultural mechanization	17. Petroleum and petrochemical technologies
8. Computers	18. Laser and fiber optics
9. Telephone	19. Nuclear technologies
10. Air conditioning and refrigeration	20. High-performance materials

3. Mathematics is a foundation of all engineering fields.
4. Modeling skills are especially important for enterprise engineering because the artifact of study (i.e., the enterprise) can only be understood, analyzed, and designed through models.
5. Analysis defined as the ability to approach a problem in a structured way with an inquiring mind.

The list is non-exhaustive but touches on what we consider the more important skills an enterprise engineer should possess.

1.3 The Enterprise Environment

In section 1.1 we described an enterprise as a system. In chapter 2, we will explore in greater depth precisely what it means to be a system; one characteristic that will be discussed is that an enterprise is an open system. As an open system, an enterprise interacts with its environment and *cannot* be understood in isolation of its environment. For this reason, it is essential to understand the enterprise's context (environment) in order to understand the enterprise as a system [29]. The enterprise environment is one characterized by dynamism – continuous, rapid, and often unpredictable change. While it is often difficult to fully appreciate how our world is changing while the changes are happening, the following main themes are ongoing: technological development, globalization, and population growth. In this section, we explore in some depth these global trends and how they affect the operation and therefore the design of enterprises.

Technology Development

The development of technology includes the improvement of previous technologies as well as the invention of new technologies. The National Academy of Engineering surveyed professional engineering societies to identify the 20 greatest engineering achievements (see Table 1.1). These new inventions greatly changed society, and in our context, enterprises.

Several of the technologies listed in Table 1.1 have greatly changed transportation. Only a few generations ago traveling across just the U.S. was difficult, never mind overseas travel. The first person to drive cross-country in a car was Dr. Horatio Nelson Jackson and his mechanic Sewall Crocker in 1903. They left San Francisco and arrived in New York 63 days later, spending some $8,000 in the process.[3] They succeeded despite the fact that there were no gas stations in 1903 and less than 150 miles of paved roads in the U.S. Today, the same cross-country trip takes about five days if you exclusively drive during daylight hours. Flying was not an option in 1903 since in that same year the airplane was only first being tested by Orville and Wilbur Wright in North Carolina.

To travel across the Atlantic or any body of water was done by boat, taking one week to cross from the U.S. to Europe. Not until 1927 did Charles Lindbergh make a transatlantic flight from New York to Paris that took him 33 hours. Commercial airlines did not really start until after World War II. The first jet airliner was the Boeing 707, which was introduced in 1959.[4] Nowadays, it is both relatively inexpensive and quick to travel from one part of the world to another. A businessman can fly directly from New York to Tokyo, have a business meeting, and be back in New York the next day.

In addition to the easy movement of people, the advances in communication and information technology make it possible to send large amounts of data around the world in seconds. Compare this to the first telephone call made by Alexander Graham Bell in 1876 in which he told his assistant, "Mr. Watson, come here, I want you." In 1915, Bell was able to repeat that same request, but over the first transcontinental telephone lines connecting the U.S. east coast to the west coast. Today, we do not think twice about calling nationally or even internationally.

Much of today's information flow is in electronic format over computer networks. Computer networking is a relatively new technology – the ARPANET, the predecessor to the Internet, only had 213 nodes in 1981 [15]. The first publicly available access to the Internet was provided by Delphi in 1992. However, growth in usage has been exponential such that nowadays almost half the population in the industrialized world have access to the Internet. Cisco forecasts monthly Internet traffic to grow from 4234 PB (pera-bytes) in 2007 to 43,551 PB in 2012 [7]. The Internet has made possible enterprises, such as Amazon.com, that exclusively sell merchandise online. Many airports, universities, and even the downtown sections of some cities have wireless wide-area networks so that anybody with a computer (or other IT device) can access the Internet.

A technology trend is the distinction between telecommunication technology and computer technology is becoming blurred. What was once exclusively a telecommunication device such as cellphones has now also become a computer device as well. People can now view webpages on their mobile phones. Likewise, computers now serve as telecommunication devices. For example, the software technology Skype enables inexpensive telephone calls using a personal computer and the Internet.

Another, related technology change is the advent of mobile technology, which has had profound impact on world cultures, especially in countries where telecommunications was under-developed. In countries such as India, cellular telephones have enabled people to "leap-frog" the conventional land-based telephone lines to acquire telecommunications service. Mobile technologies has made information technology ubiquitous because it is no longer found in defined places: no longer must telephone calls be made from the home or the office. For example, email is no longer limited to office hours because workers can send and receive emails even while vacationing on a Caribbean beach (whether they want to is another matter).

The change in technology has changed our lifestyles, our social interactions, our culture, and of course how enterprises interact with their environment. For example, IBM has teams that work together but rarely meet face-to-face. A manager might be located in Miami, the

[3]Peter Firmrite, Long before the interstates, there was a Winton, *San Francisco Chronicle*, June 16, 2003.

[4]Heppenheimer, T.A. *Turbulent Skies: The History of Commercial Aviation.* New York: John Wiley, 1995.

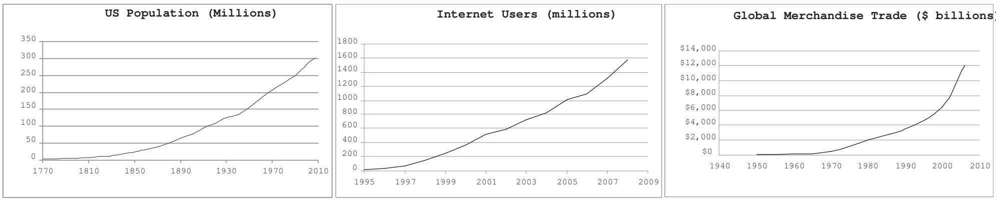

FIGURE 1.4
Examples of exponential growth.

systems analysts might be in Ohio, and the client might be in Barbados. They are able to work together due to the low cost, speed, and ease of communication and travel. In India's Kerala state, the economist Robert Jensen found that the fishermen adopted mobile phones, which attests to the ubiquity of new technology. Using mobile telephones the fishermen increased market efficiency by improving the flow and availability of information leading to a reduction in wasted fish catch, increased profits, and the lowering of consumer prices.[5] These are but two examples of how technology has affected enterprises.

Globalization

Globalization is a term describing how barrier after barrier to the world-wide flow of materials, information, people, and knowledge are disappearing or no longer becoming relevant. Especially pertinent to enterprises is the growth in global trade, emergence of a uniform global market, and ability to source labor and materials globally.

Figure 1.4 shows that global merchandise trade has grown from $62 billion in 1950 to $9 trillion in 2004. In many nations, the percentage of the gross domestic product attributed to imports and exports has grown (see Figure 1.4). The tremendous growth of global trade is due to technological advances, political enablers, economic enablers, and social factors. Technological advances have simultaneously decreased the cost and increased the speed of the physical transportation of goods, transmission of information, and capital. Trade agreements made through organizations such as the World Trade Organization (WTO) and regional agreements such as the North American Free Trade Agreement (NAFTA) have reduced tariffs. Also, there has been a convergence in standards so that products can more easily be sold in different countries.

The globalization of trade has an immediate, clear impact on enterprises. Today's enterprise competes in a global marketplace, which for most industries means greater competition on price, quality, performance, and speed. To illustrate, consider Ford, which competes in its home market of North America against foreign brands from Japan, Korea, Germany, and elsewhere. In 2008, Ford's North American market share was 15.2% compared to Toyota which enjoyed a 16.4% market share. Ford also competes outside of North America; in 2008 more than half of Ford's sales are from outside of North America.[6]

The example of Ford raises questions about the nationality of a corporation. Ford is considered a U.S. corporation because it is headquartered in the U.S. and files U.S. financial report. Yet it operate facilities around the globe selling to customers around the globe. Ford is an example of a multi-national corporation. Some multi-national corporations retain an ethnocentric perspective of their home country, in which they think and operate as if they were in their home country. Others adopt a global perspective in which they act

[5] Cellphones bridge the digital divide, *The Times of India*, Jan 29, 2006.
[6] 2008 Ford Annual Report.

independently of geography, working according to local languages, customs, and traditions. ABB, headquartered in Switzerland but operating in more than 100 countries is an example of the later perspective.

We can say that globalization has a disrupting influence in that it is changing the world. Placing a value statement on the change is more difficult and depends on the context and perspective adopted. In Thomas L. Friedman's best-selling book, *The World is Flat,* he suggests that globalization is beneficial for all people. Such a generality greatly simplifies a highly complex phenomenon. Globalization has led to increased worldwide trade and also increased wealth in many nations, but that wealth is unevenly distributed [33]. The increase of global trade has contributed to the increased inequality within a country between the richest and poorest [8] [9]). The Gini coefficient, a measure of income inequality in which the higher the coefficient the less equal the society, shows the U.S. going from 0.395 in 1974 to 0.463 in 2007. In the U.S. the median full-time male workers' income has been essentially unchanged between 1978 and 2007 [2]. However, in any complex system, there are many factors that influence income disparity – in the U.S. this includes immigration, de-unionization, changing family structures, relative size of agricultural work sector, and other changes. Technology also contributes to the disparity in that more educated, higher-income individuals reap greater benefits from technology.

Other effects of globalization include the erosion of local distinctions and culture (see [27]) with the paradox of people simultaneously feeling greater affinity towards their own group. This may be a benefit to many enterprises because it reduces the need to customize products for different markets. If the same product or service can be sold worldwide without change, then economies of scale can be achieved to reduce overall operating costs.

Population Growth

The world population has grown tremendously in recent human history. It has grown from 2.5 billion people in 1950 to 6 billion in 2000. Further growth is projected such that the world population will be 7 billion in 2012.[7] Even with a decreasing growth rate, total population will continue to grow for the next generation. The repercussions of this growth are many. Concerning enterprise, a growing population means more people demanding products and services. Moreover, concomitant with population growth has been an increase in the quality of life for much of the world. More and more citizens of what were previously poor countries have greater incomes and are using their income to consume more and more resources. However, the second effect of the growing population is that the products we consume are built from raw materials and resources that are ultimately limited.

The world has seen rapidly rising costs for food, raw materials, and fuel.[8] This is a natural result of having limited resources sought after by a rapidly growing population. Some authors have suggested that the world will reach these limits on resources as predicted by Thomas Malthus in his *Essay on the Principle of Population* in 1798.

What is needed is to control world population and to better utilize resources. These challenges will affect enterprises in many ways. For example, the high cost of fuel has made some U.S. manufacturers look at sourcing parts locally to avoid the high cost of transporting goods from locations in Asia.[9] Changes in commodity prices are causing enterprise to consider substitutes for various materials, rethink how they utilize resources, and pay greater attention to sustainability.

[7] Source: U.S. Census Bureau, International Database, June 2008 Update, www.census.gov.

[8] Jeffrey D. Sachs, How to end the global food shortage, *Time Magazine*, April 24, 2008; Vivienne Walt, The world's growing food-price crisis, *Time Magazine*, February 27, 2008.

[9] Stung by Soaring Transport Costs, Factories Bring Jobs Home Again, by Timothy Aeppel, *Wall Street Journal* June 13, 2008; Page A1; China's Outsourcing Appeal Dimming, by Ariana Eunjung Cha, *Washington Post*, 8 September 2008.

Global Environment's Effect on Enterprises

The trends of technology development, globalization, and population growth all interact and affect the design of enterprises. Some of the ways in which these trends affect enterprise are:

- Global competition means that local markets are essentially international markets. Enterprises must compete for market share against both local and international enterprises.
- Information and knowledge flow freely across borders. In some cases this causes problems because of the limited protection in some nations for intellectual property. It also means that competitive advantage is often temporary because competitors can learn and copy best practices from around the world. On the beneficial side, it means that enterprises can operate globally far more efficiently and better integrate their supply chains.
- Markets change rapidly so enterprises need a quick payback on investments before the market opportunity, technology, or environment changes. Enterprises must continuously grow and improve in order to compete in rapidly changing environments.
- Population growth and limited resources have made sustainability the keyword for many industries. *Sustainability* means the adoption of practices so that natural resources are not depleted in a way that reduces the ability to continue those practices.

In addition to these global trends that affect all enterprises, each enterprise will be affected by more local, industry-specific or geographic-specific forces.

It is difficult for us to envision how the world will change in our lifetime. Most of the trends outlined above are exponential. Unfortunately, according to the science-fiction writer Robert Heinlein, most people can only extrapolate that the current level of technology will continue or slightly change, few people will even consider progress at the current rate, and even fewer are willing to make predictions for a continuation of exponential progress, which is precisely what the world has experienced over the past 50 years.[10] Gordon Moore, a co-founder of Intel, predicted that computing power would double approximately every two years – this is exponential growth, which has proven accurate to date!

As this section opened, it was declared that the enterprise environment is dynamic. In the past century, technology changed, political thought changed, society changed, and of course the enterprises in society changed. We cannot foresee what future changes will occur. What we can foresee is that there will be change and that the change is happening far faster than it ever has in the history of human existence. What this calls for are enterprises that are agile so that they can constantly change and improve with their environment. An agile enterprise scans its environment and understands how it is changing, how those changes may affect its operations, and makes design choices in order to work within that environment. In Chapter 4 on enterprise design methods, we discuss agility in greater depth.

1.4 History of Enterprise Engineering

Early work addressing the design of enterprise is to be found in many different disciplines. In this section, we outline some of the main intellectual influences on modern-day enterprise engineering.

[10] Heinlein, R.A., *Expanded Universe*, Berkley Publishing Group, New York, 1982, first paperback edition, p. 323.

1.4.1 Scientific Management

Adam Smith (1776) in his book *The Wealth of Nations* discussed how the division of labor could dramatically increase productivity. He noted that breaking work up into small discrete jobs simultaneously makes the job simpler, enables specialization, and allows workers to become highly skilled and efficient at the job assigned to them. During this same period, the concept of interchangeable parts emerged. Interchangeable parts are enablers for the division of labor. These ideas and changes in technology established an intellectual environment that has influenced work design to this day: work is broken up into simple tasks that are repetitively done by workers.

During the Industrial Revolution (1850-1950), emerged the Scientific Management movement, which strongly influenced thought on how to best organize an industrial organization. *Scientific Management* is the application of the scientific method to management. The primary goal of scientific management was to achieve efficiency of resources. Time and motion studies to improve labor efficiency, use of machinery to increase productivity, as well as division of labor characterize the general concepts of Scientific Management. Scientific Management led to the founding of the academic discipline Industrial Engineering, whose curriculum still strongly bears the mark of Scientific Management theory.[11]

It is important to review the times and environment under which the ideas of scientific management were developed. There was a social migration of people to urban areas from rural agricultural areas of the county, as well as an influx of new immigrants from Europe. Cheap and unskilled labor was plentiful. Manufacturing, the main generator of wealth, required large amounts of labor to manufacture the products they sold. These circumstances strongly influenced the development of scientific management. First, the progenitors of scientific management took labor for granted; if one worker did not perform well, there were others to take his place. Given this attitude it is not surprising that worker satisfaction was not a priority or even considered in the design of work. Second, many of these new workers had little education or training. So the division of labor was partly done to create unskilled production jobs these workers could fill. The simpler the job then the easier it was to fill the job with the available labor. The separation of the planning of the work from doing the work also flowed from these circumstances. So, we need to remember the social and economic environment that influenced the thinking that went into the development of Scientific Management.

The ideas of Scientific Management were developed by Frederick Taylor, Gilbreth, and others. Frederick Taylor was an engineer who became a well-known advocate of scientific management. Taylor wrote,

> And this one best method and best implementation can only be discovered or developed through scientific study and analysis... This involves the gradual substitution of science for "rule of thumb" throughout the mechanical arts.

In Taylorism, as it is sometimes referred, there is a sharp division between physical work and cognitive work. Taylor strongly believed that the successful manager was a manager who controlled every aspect of the production process. To achieve this, managers should uncouple planning and execution – i.e., workers only execute what managers plan. This is probably the most well-known principle of Scientific Management (the other principles are listed in the box below. At a lecture he gave in 1906, Taylor explained, "In our scheme, we do not ask for the initiative of our men. We do not want any initiative. All we want of them is to obey the orders we give them, do what we say, and do it quick" ([17] p. 169).

[11] Although interviews of senior faculty by Bailey and Barley [4] suggest Taylor had less of a role in shaping the Industrial Engineering curriculum than many have thought.

Principles of Scientific Management

1. Time studies
2. Functional supervision
3. Standardization of tools and implements
4. Standardization of work methods
5. Separate planning function
6. Management by exception principle
7. The use of slide-rules and similar time-saving devices
8. Instruction cards for workmen
9. Task allocation and large bonus for successful performance
10. The use of the "differential rate"
11. Mnemonic systems for classifying products and implements
12. A routing system
13. A modern costing system

In Scientific Management, the work is systematically analyzed, it is broken down into its minuscule operations, each operation is assigned to a separate worker, and an elaborate set of procedures is generated to regulate each operation. In this approach, there is a sharp division between the planning work and the actual labor itself. This principle is famously illustrated by the story of when Taylor analyzed shoveling. He determined the proper size shovel for various materials (coal, dirt, rock, and so forth). The worker as a result was no longer allowed to choose which shovel to use. Taylor demonstrated that the productivity of the worker was greatly increased.

Henry Ford expanded on the ideas of scientific management by adding the revolutionary idea of having a moving assembly line. In 1913, the Ford Motor Company reengineered their Highland Park automobile assembly operations and cut production time from 750 minutes to 90 minutes per car through work simplification, division of labor, the moving assembly line, and other means.[12]

Henri Fayol, a contemporary of Taylor, proposed general principles of management. These ideas continue to strongly influence management thought up to the present day [37]. The work of Taylor and Fayol is essentially complementary. They both realized that the problem of human resource management is the key to business success. Both applied the scientific method to the problem of management. Taylor worked primarily on the operative level, from the bottom of the organizational hierarchy upward. Fayol concentrated on the Managing Director (his term) and worked downward. Unlike Taylor, Fayol's work reflects a tension between his recognition that managers are not supermen and yet employees should not be allowed enough autonomy and responsibility to solve second-order problems (problems for which there are no precedents, or previous exemplary solutions). Many of Fayol's principles still make sense today. For example, it is still important that if somebody is held responsible for something, then that person needs the authority to ensure its success. Other principles such as discipline need to be adapted to the expectations of society today.

[12] http://www.ford.com/about-ford/heritage/places/highlandpark/663-highland-park.

Fayol's Principles of Management

Division of work. Management should pursue standardization of work so that it can be divided among workers who specialize in a narrow set of tasks. The objective is to produce more and better with the same effort.

Authority and responsibility. The good manager should have official authority deriving from office and his personal authority. Responsibility is a corollary of authority, it is its natural consequence and essential counterpart, and where authority is exercised responsibility arises.

Discipline. Discipline is obedience, behavior, and respect. Discipline is absolutely essential for the smooth running of business and without discipline no enterprise could prosper.

Unity of command. An employee should receive orders from one superior only.

Unity of direction. One head and one plan for a group of activities having the same objective (centralization of authority).

Subordination of individual interest to general interest. The interest of the home should come before that of its members and the interest of the state should have pride of place over that of one citizen or group of citizens. Constant supervision is needed to ensure that the general interest will not be lost in favor of individual interest.

Remuneration of personnel. Remuneration should be fair. It shall not go beyond reasonable limits.

Centralization. Centralization belongs to the natural order. The degree of centralization must vary according to different cases. If the moral worth of the manager, his strength, intelligence, experience and swiftness of thought allow him to have a wide span of activities, he will be able to carry centralization quite far and reduce his seconds-in-command to mere executive agents.

Scalar chain. Describes the chain of superiors ranging from the ultimate authority to the lowest ranks. In short, it is the line of authority. It is an error to depart needlessly from the line of authority, but it is an even greater one to keep to it when detriment to the business ensues. An employee who cannot obtain guidance from a superior should have the initiative to choose a course of action best suited for the organization. Such a course of action is based on precedence set by the management.

Order. In the case of material things – A place for everything and everything in its place. In case of human order – A place for everyone and everyone in his place.

Equity. For the personnel to be encouraged to carry out duties with all the devotion and loyalty of which it is capable it must be treated with kindliness, and equity results from the combination of kindliness and justice.

Stability of tenure of personnel. Generally, the managerial personnel of prosperous firms is stable, that of unsuccessful ones is unstable. Moreover, stability of workers is beneficial. Time is required for an employee to get used to new work and succeed in doing it well. If when he has got used to it, or before then, he is removed, he will not have time to render worthwhile service.

Initiative. Thinking out a plan and ensuring its success is one of the keenest satisfaction for an intelligent man to experience. It is also one of the most powerful stimulants of human endeavor. Hence, it is essential to encourage and develop this capacity to the fullest.

Esprit de corps. Harmony and a sense of belonging to a group is great strength to the organization. Effort, then, should be made to establish the esprit de corps.

1.4.2 Humanist School

The humanist school of management of the early and mid-1900s tried to shift the focus of organization from processes to people [22]. Mayo, who was trained as a sociologist, viewed man as a social and emotional being, and argued that if you treated the workers with respect and tried to meet their needs, then they would be more productive workers. The experiments he led at Western Electric's Hawthorne Works illustrate the basic ideas of motivation that he developed. These experiments, called the Hawthorne Experiments, studied how changes to work conditions such as hours per week, number of rest breaks, time of lunch, and similar changes affected productivity. In the experiments, they found productivity increased regardless of the interventions they made – productivity even improved when the workers were returned to their original, harder work conditions. These experiments do not support the one best way advocated by Taylor, and point to a more complex view of human motivation and performance. Workers at Hawthorne were simply responding positively to the attention from management.

Scientific Management ignores or minimizes those traits that make humans, human. The Humanist School was to some extent a reaction to the Scientific Management approach that viewed man mechanistically. The main criticism, still echoed today, is that Scientific Management leads to repetitious, tedious, and boring jobs that diminish the workers' self-being. The Humanist School, on the other hand, argued that through job enrichment and promoting worker satisfaction then organizational benefits could be realized.

Maslow [21] categorized human needs in a hierarchy starting at the bottom with physiological needs (food, water, shelter), safety, belonging, self-respect, and what he termed self-actualization. He argued that lower-level needs must be satisfied prior to high-level needs. Under a Taylorist approach in the late 1800s through the early part of the 1900s, an enterprise would satisfy the physiological needs and, later, also safety.[13] Following WWII many corporations satisfied belonging and for some workers self-respect. Self-actualization is less common, but is argued by some authors that enterprises should strive to design work so that all workers can attain a level of self-actualization that will also benefit the enterprise [20].

This early work led to the mostly accepted job characteristics theory articulated by Hackman and Oldham [14, 24]. The job characteristics theory posits that five job characteristics produce a psychological state in the job holder that affects job outcomes including performance. The five job characteristics are skill variety, task identity, task significance, autonomy, and feedback. Skill variety is when the job requires a wide variety of the worker's skills and abilities. Task identity is when the worker develops a sense of ownership and responsibility for a meaningful part of the job. Task significance is the degree to which the job impacts the lives of others. Autonomy is the degree of freedom and independence the worker has in deciding how to carry out the work. Feedback is the degree to which the worker received knowledge of the results of his or her work.

These five job characteristics are theorized to affect the worker's psychological state, which in turn affects four outcomes of internal work motivation, growth satisfaction, general satisfaction, and work effectiveness. How and the degree to which they affect these outcomes is moderated by the workers' growth need strength, defined as the need for personal accomplishment. Workers with a high growth need strength react more favorably to enriched jobs. This model better represents the complexity of the human situation. There are many factors that influence worker satisfaction and the link to job performance. Because each worker is an individual then not all workers will react in the same way.

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[13] Concern over industrial safety is a recent development. In the 1870s, during the building of the Brooklyn Bridge between 30 and 40 workers died, including its chief engineer John Roebling. – p. 506 in *The Great Bridge* by David McCullough, Simon & Schuster Publisher, 2001.

The Volvo assembly plant in Uddevalla, Sweden is a prominent example of the human relations school. Volvo put into practice what is called the Human System Design by having small teams of skilled workers assemble complete cars from start to finish. The approach turns the ideas of Smith, Taylor, and Ford on its head. A motivation for Volvo to experiment with alternatives to the assembly line was the difficulty they experienced in recruiting and retaining workers. Sweden, at the time in 1990, had a very low unemployment rate of 1.1%. A more humanist work environment was seen as necessary to attract workers.

Volvo closed the Uddevalla plant in 1993 [32], critics saying it never matched the productivity of other assembly plants, although there are many factors that may have come into play for Volvo's poor performance (poor car design, marketing, etc.). In Volvo's Uddevalla plant, it took 16 months of training for a worker to master the assembly work ([26] p. 90); contrast this with Ford's idea of training workers in simple tasks in a matter of hours. In 1990, it took 50-55 man-hours to assemble a car in the Uddevalla plant ([26] p. 150). The best automotive assembly plants were assembling cars in 13.5 man-hours ([36] p. 120). However, a controversy persists over the performance of the Volvo Uddevalla plant because direct comparisons of plants in different geographic regions is difficult, and there are many other factors that played a role in Volvo's decisions; such as the more important management-stated objective to reduce capacity, rather than to close the plant due to poor efficiency.

1.4.3 General Systems Theory Movement

The Scientific Management approach breaks down the production process into simple tasks and then improves the efficiency of each task. This is called a reductionist approach, and it still widely permeates current engineering practice. A different approach is the systems approach that looks at the whole. Bertalanffy, an important researcher of the systems movement and others contributed to the General Systems Theory that says, "the whole is greater than the sum of its parts." What this statement means is the behavior of the system cannot be explained from the behavior of its constituent parts. The system characteristics emerge due to the interaction of the parts. This lead Bertalanffy to propose the existence of general system laws that apply to any system, irrespective of the particular system, its properties, or the elements involved. Bertalanffy was motivated, in part, by the trend towards even greater reductionism and specialization in science. Against reductionism, he said [5], "It is necessary to study not only parts and processes in isolation, but also to solve the decisive problems found in organization and order unifying them, resulting from dynamic interaction of parts, and making the behavior of the parts different when studied in isolation or within the whole...". And against specialization, "Modern science is characterized by its ever-increasing specialization, necessitated by the enormous amount of data, the complexity of techniques and of theoretical structures within every field. Thus science is split into innumerable disciplines continually generating new sub-disciplines. In consequence, the physicist, the biologist, the psychologist and the social scientist are, so to speak, encapsulated in their private universes, and it is difficult to get word from one cocoon to the other...".

Two important observations can be drawn from the systems science movement. First, the relationships between the parts of the system are important to the overall system behavior. For this reason, a reductionist approach might fail because it does not account sufficiently for these relationships. Second, an open system interacts with its environment, and these interactions need to be included in the analysis.[14]

[14] Some authors define analysis as strictly being reductionist. We do not use the term in that way. Later in this book we define analysis, which can be either reductionist or not.

1.5 Summary

To summarize, enterprise engineering is a discipline that views the enterprise as a product that is purposefully designed. A basic premise of this book is that enterprise engineering is a scientific endeavor in its own right; enterprise engineering has an established theoretical basis with domain-specific knowledge. This knowledge includes:

- An enterprise is an open system.
- An enterprise has a life-cycle describing its evolution from conception to retirement.
- The enterprise design method and complex problem-solving method.
- How to conduct enterprise projects.
- Understanding of how an enterprise interacts with its environment.

Enterprise projects usually only address limited aspects of the enterprise. For this reason, we argue it is important to have an enterprise architecture to ensure all enterprise projects conform to an overall enterprise design. To conduct a project, there is an enterprise design method that describes the phases, techniques, and management of these large projects.

This chapter reviewed the historical development of enterprise engineering, tracing its roots to scientific management, humanist school of management, and general systems theory. Current approaches to enterprise systems build on these foundations. Scientific management ideas on efficiency still have great influence on how we design enterprise systems, but it is tempered by a knowledge that humans are important elements of the system that cannot be treated simply as machines. General systems theory introduced ideas on feedback, open versus closed systems, and other system principles that apply to enterprise systems and are discussed more fully in the next chapter. The concepts of the human relations school did not replace the earlier scientific management school, nor has the more recent systems thinking school replaced the human relations school. The older ideas are not abandoned by incorporated into the new ideas. Division of labor and work simplification do improve productivity. But now we also consider the other aspects of the job as well. Consequently, work designers trade off the benefits of smaller tasks versus job enrichment, and the resulting decision depends on the particular case being considered.

Review Questions

1. Describe how many enterprise systems are designed today.
2. Why do we use the term “enterprise” instead of organization?
3. What makes a virtual enterprise different from other enterprises?
4. List the steps involved in a general problem-solving methodology.
5. What is the high-level design of an enterprise and who creates it?
6. In a project that redesigns the inventory control for a manufacturer, identify who the stakeholders are.
7. Argue whether a project that replaces a manual process to do purchase orders with an on-line, web-based system should be called business process reengineering.
8. What is the primary distinction between an enterprise architect and a system architect?

9. Explain how enterprise engineering is different from systems engineering.
10. Explain why it is important to understand the enterprise's environment.
11. Describe the primary goals of scientific management.
12. Take one of the fourteen principles of scientific management and describe how it is, or is not used today in business.
13. A worker in a fast-food restaurant has the job to assemble hamburgers. Assess this job using Maslow's hierarchy of needs.
14. Choose a business (e.g., fast-food, automotive manufacturing, textiles, televisions) and describe how globalization is affecting that business.
15. Explain the difference between "enterprise system" as used in the book and "enterprise system" as when referring to enterprise resource planning systems.
16. Describe how BPR differs from Continuous Process Improvement.

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