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Introduction

The only constant is change, continuing change, inevitable change that is the dominant factor in society today.

Isaac Asimov

This Enterprise Dynamics Sourcebook is the product of The MITRE Corporation’s (MITRE) Sponsored Research Program and a range of published applications that pertain to enterprise transformation programs. As a sourcebook it draws on a series of published papers and reports documenting case studies that provide a starting point for a new discipline of enterprise dynamics as a core capability of enterprise systems engineering (ESE). This case study approach captures the diversity of transformation environments and the evolution of methods to deal with this emergent challenge to government and private sector enterprises. Just as fluid dynamics and structural dynamics advance other engineering practices, enterprise dynamics advances the practices of systems engineering at the enterprise level and enterprise architecting, enabling the enterprise systems engineering and architecting (ESE/A) process described in Chapter 5, Section 5.8 and drawing on tools and methods described throughout Section I.

Rapidly changing market, technological, and organizational environments pose complex challenges to government and private enterprises that must improve services and transform their processes, organizations, and resource base. Planning and management of such extensive transformation require extended management tools and methods that deal with the dynamics of change. This sourcebook provides a foundation and examples of methods that deal with the emerging complexities of enterprise transformation involving the coordination of policies, organizations, economics, and technology (POET) in operational strategies and processes. In its original formulation, the “O” in POET designated operations; here it is used to designate organizations, thus giving greater emphasis to organizational issues, as the major theme of ESE/A is transformation of operational capabilities, and recognizing the importance of managing organizational change in coordination with other transformation activities. Throughout this sourcebook enterprise dynamics focuses on the mission and business operations of the enterprise.
Introduction

The concepts discussed in this sourcebook are applicable to both government and large private sector enterprises that involve significant service or regulatory interactions with government entities and must transform to operate effectively in this complex ever-changing environment.

Dynamic phenomena are a very important part of all organizational theories and engineering disciplines and are a central theme of the analytic case studies in this sourcebook. In these enterprise dynamics case studies, we describe and apply frameworks and analytical models to a range of enterprises to improve the understanding of their dynamic elements and interactions. Specific enterprise transformation efforts must involve all of the POET elements over the full life cycle of transformation with a balance appropriate to the specific enterprise. Planning, implementing, and managing the transformed enterprise require multiple skills and methods. Just as dynamic analyses in engineering and the social sciences draw on a wide variety of methods applicable to specific challenges, the applications described here were selected to introduce a wide range of methods that have demonstrated their utility for the analysis of enterprise dynamics.

The sourcebook is directed toward analysts, managers, and decision makers engaged in significant transformation of their enterprises to operate at high performance levels in the delivery of products and services. The concepts apply in the public and private sectors and address the inherent technical, social, economic, and management complexities of enterprise operations and transformation in a global economy. It is written with the belief that qualitative and quantitative analytical methods drawn from systems engineering and management science can inform the managers of enterprise transformation programs and reduce their risks and unacceptably high failure rates.

Working Definition of an Enterprise

An enterprise is a purposeful social, technical, and economic undertaking designed to create value for its stakeholders involving:

- Policies, organizations (people), economics, and technology interacting with each other and their environment in operational processes as a complex system-of-systems to achieve goals
- An organization (single or multiagent, and possibly virtual) created for the undertaking
- A readiness to embark on bold new ventures

The dynamics of an enterprise are highly dependent on the mission or business characteristics (the enterprise landscape) and the perspective of the enterprise required to address management issues and inform decision making (operational, scalar, and temporal perspectives).
The case studies in Section II represent enterprise “purposeful undertakings” at multiple scales ranging from a commercial business strategy, through technology challenges, an operations control center, and agency activities, to national programs for the transformation of healthcare and the U.S. energy system.

**Working Definition of Enterprise Transformation**

The transformation of an enterprise to a desired future state is a comprehensive, managed change process driven by public (consumer) demands, competitive factors, economic forces, and technological opportunities. The primary transformation objectives are significant performance improvements and the effective coordination of policies, organizations, economics, and technology in operational strategies and processes. Performance improvements include better products and services, cost, and quality. The dynamic and iterative change process and key elements may be portrayed as shown in Figure 0.1.

The agile sense-and-respond enterprise is quick in sensing and responding to external events and trends and is in a constant state of transformation given the pace of socioeconomic change. This transformation requires proactive analysis of the dynamic interactions among policies, organization, economics, technology, and the environment, incorporating inherent risks and uncertainties.

Each of the case studies in Section II represents unique transformation challenges and draws upon applicable models and approaches from those described in Section I.

The initial chapters in Section I describe the scope and complexities of enterprise transformation as well as approaches to planning and managing that transformation, including ESE/A and the supporting discipline of enterprise dynamics. These emergent and comprehensive methods extend systems engineering and architecting into the complex enterprise environment to address the coordinated evolution and transformation of all POET elements of the enterprise to adapt to changing public demands and expectations, and to take advantage of technical and organizational opportunities. This is the most recent stage in the long-term continuous

![Diagram](image_url)

**Figure 0.1** Goal: Transformation to an agile sense-and-respond enterprise.
evolution of systems engineering to address issues of increasing complexity, in this case enterprises operating at a national and global scale involving multiple partners and stakeholders, divergent interests, and a high degree of risk and uncertainty.

Section I also presents a selection of analytical tools and methods (models) that deal with specific complexities of transformation addressed through ESE/A. Collectively the tools and methods establish an initial foundation for ESE/A and the supporting discipline of enterprise dynamics, an emergent and comprehensive field that extends systems engineering and architecting into the complex enterprise environment.

Section II presents a series of ESE/A case studies based on published papers and reports on modeling the complex dynamics in specific enterprise-level applications to address critical issues in the acquisition of new operating capabilities. They represent enterprise transformation challenges at a scale where the government role is paramount and, in some of the applications presented, with significant private sector and consumer involvement. The case studies employ a variety of modeling and analytical methods as appropriate to the specific enterprise transformation challenge they are addressing. Examining this variety in the context of the ESE/A process provides valuable and practical guidance for management and problem solving.

Concepts and characteristics of complex systems and megasystems were introduced in an enterprise context by Hybertson (2009), Stevens (2010), and Rebovich and White (2010). This sourcebook supplements those concepts. It describes a discipline of enterprise dynamics incorporated in an ESE/A process to address the planning, design, and management of complex enterprises and megasystems in a very challenging technical, social, and economic environment. Illustrative applications pertaining to a range of enterprise domains are summarized to demonstrate how the process can be tailored to specific enterprise challenges with a focus on mission performance. A top-level summary of the sourcebook chapters is presented below. Each chapter title is followed by key concepts within the chapter.

Section I: Foundations and Conceptual Frameworks

Section I of this sourcebook establishes the foundations of ESE/A and the supporting discipline of enterprise dynamics, an emergent and comprehensive field that extends systems engineering and architecting into the complex enterprise environment. This is the most recent stage in the long-term continuous evolution of systems engineering to apply quantitative and qualitative methods to issues of increasing complexity, in this case enterprises operating at a national and global scale involving multiple partners and stakeholders, divergent interests, and a high degree of risk and uncertainty.

The discipline of ESE/A merges system engineering with management science, enhancing current concepts of enterprise architectures (EA) to deal with increasingly complex challenges faced by government agencies and large commercial enterprises. The emphasis is on describing, analyzing, and evaluating dynamic behaviors of complex techno-socio-economic systems, with all of the POET elements of the
Enterprise working together for effective operational purposes (enterprise dynamics). Several methods are described for dealing with complexities, risks, and uncertainties to provide a robust adaptive approach to planning and implementing major national and international programs.

Chapter 1: Defining Enterprise and Transformation Challenges

The enterprise definition that best captures the transformation theme and the range of scales addressed is: an entity engaged in a purposeful undertaking that involves internal and external stakeholders, and operates as a complex adaptive system involving policy, organizational, economic, and technology dimensions. This working definition clearly includes complex systems and megasystems and establishes a scope that encompasses a broader boundary that includes all stakeholders rather than just an individual organization. This broad definition can include specific agencies with a complex mission, multiagency initiatives, or virtual organizations that come together for a specific purpose. The transformation challenges that are outlined establish the need for an improved planning and management process that incorporates enterprise dynamics. Effective governance of the enterprise and transformation programs is critical to success and this aspect of a management structure is discussed in Chapter 5 as a wrap-up to Section I. Decision support and resource management for such enterprises can be improved by systems engineering and architecting methods applied at the enterprise level: ESE/A.

Chapter 2: From Systems Engineering to Enterprise Systems Engineering

An historical perspective illuminates the long-term evolution of the field of systems engineering in response to public and private sector challenges and leads up to a foundation for the enterprise systems engineering methodology as described in a following chapter. This evolution involves increasingly complex challenges and evolving tools and methods for planning and analysis. Historical examples reveal a tendency toward technical hubris in expecting more than the methods are capable of delivering, a warning that the enterprise systems engineer must draw upon management and organizational theory and approaches to decision making under uncertainty, in addition to other analytical methods that serve to describe and analyze complex systems.

Chapter 3: Foundations of Enterprise Systems Engineering and Architecting

The current state of evolution in enterprise systems engineering and enterprise architecting is reviewed in this chapter and is extended to portray an integrated approach to ESE/A drawing on concepts of enterprise dynamics. Managing
and enhancing the performance of public and private enterprise activities are the subject of architecting, modeling, and simulation applying the disciplines of management science, probability theory, organizational theory, systems engineering, and socioeconomics. Each discipline addresses specific dynamic elements of the enterprise from a unique perspective and contributes a robust foundation for ESE/A that addresses the complexity and dynamics of the interacting POET elements of the enterprise. This field has been fertile ground for research and applications over the past few years and is sufficiently mature to identify foundational concepts.

Chapter 4: Enterprise Dynamics Methods and Models

This chapter summarizes a diverse set of enterprise dynamics methods and models that have been applied in the ESE/A applications summarized in this sourcebook. They constitute a representative sampling of the differing perspectives across disciplines applied to a range of enterprise challenges, and comprise a new discipline of enterprise dynamics (or perhaps a subdiscipline in the larger ESE/A context). Emphasis is placed on characterizing the complexities of enterprise transformation to guide the selection and creative application of appropriate tools and methods. The presentation flows from specific methodologies (source modules) to analyze dynamic effects, through the unifying time-dependent state-space descriptors of the enterprise, to the concept of an enterprise model that reflects the factors critical to enterprise transformation and the reality that some of these factors can be controlled, some can be influenced, and some are uncontrollable (the controlled, influenced, and uncontrolled [C-I-U] formulation). Multidisciplinary methods are particularly relevant to address the desired scope of policy, organizational, economic, and technical factors that must be coordinated in successful transformations of enterprise operations.

Chapter 5: Managing Enterprise Transformation Using ESE/A

This chapter describes how enterprise dynamics methods and the enterprise systems engineering and architecting (ESE/A) guidelines can provide value by relating the modeling and simulation methods to state-of-the-art management tools such as EA, activity-based management (ABM), and enterprise resource planning (ERP) systems. This architecture-based approach for governance of enterprisewide operations and transformation encompasses the POET elements and facilitates the engagement of technical, financial, and business managers in the operational and transformation processes. Architecture templates are described to couple dynamic analytical methods with ABM techniques to coordinate planning and management across the multiple agencies and stakeholders involved in complex undertakings. In this governance environment, enterprise resource management (ERM) accounting systems can be used to capture an always-current “state-space” description of
financial and tangible resources of the enterprise. The approach is described using transformation examples that involve the coordination of multiple agencies (or firms). The multiagency environment is an increasingly important challenge for the enterprise, public or private, that operates in complex national and global markets with extended supply chains or reach.

The management approach is supported by ESE/A guidelines that can be tailored to specific enterprise transformation challenges. The diverse tools and methods described earlier must be selected and applied in a way that is appropriate to the scale and complexity of the ESE/A challenge. The ESE/A enabling process described here provides the necessary guidelines, and is based on experience with transformation programs, examples of which are described in the Section II case study applications. The process is flexible and adaptive in addressing the challenges and uncertainties in managing the transformation of complex enterprises in their unique forms.

Section II: Enterprise Modeling Approaches and Applications

In Section II, we present a series of ESE/A case studies based on published papers and technical reports on modeling the complex dynamics in specific enterprises to address critical issues in the acquisition of new operating capabilities. The case studies represent enterprise transformation challenges at a scale where the government role is paramount but with significant private sector and public involvement. The case studies employ a variety of modeling and analytical methods as appropriate to the specific enterprise transformation challenge they are addressing. Examining this variety in the context of the ESE/A process provides valuable and practical guidance for management and problem solving.

The case study applications are organized in relation to the defined scale of the enterprises starting with single agencies and corporations, and progressing through complex mission operations to multiple agencies and complex challenges of national scope with significant impacts on the economy. These are summarized in the following chapter descriptions.

Chapter 6: Simulation of Enterprise Architecture for a Business Strategy

This chapter applies the coupling of enterprise architecting and enterprise dynamics to strategic planning at the corporate level. The results of alternative investments of discretionary funds in business development and R&D are analyzed. This case study represents a major step forward in the foundational discipline that supports ESE/A through the concept of dynamic architecting. The application described implements
a dynamic model and simulation with the comprehensive structure of an EA as defined by federal and commercial EA guidelines. This approach overcomes a major deficiency in the static nature of most architectures by joining this widely practiced enterprise planning and management method with enterprise dynamics.

**Chapter 7: Reasoning on Technology Uncertainties for Enterprise Transformation**

This chapter describes a method for reasoning about the likelihood of attaining a specified desired performance resulting from emerging dynamics and uncertainties within an enterprise or its environment. A basic principle is that mission performance occurs due to individuals understanding the dynamic interactions of people, process, and technologies. Individuals reason about dynamic interactions producing insights on likely performance attainment given the interactions. Individuals increase their understanding and their subsequent decisions and actions are changed because of their improved understanding.

The method uses evidential reasoning and multientity Bayesian networks (MEBN) to compose arguments about the relationship of technology initiatives to strategic outcome attainment. A federal program example illustrates the method.

**Chapter 8: Optimal Control and Differential Game Modeling of a Systems Engineering Process for Transformation**

This case study describes a unifying analytical framework for modeling enterprise dynamics in the ESE process across a range of enterprise and program types, and is demonstrated on a specific transformation program. The framework is a control-theoretic formulation that uses state and control parameters relating to the enterprise, stakeholders, and the environment with which the enterprise interacts. The framework expresses the individual self-interests of stakeholders and environmental players as a differential (dynamic) game, which is explored and interpreted in terms of game-theoretic Nash equilibrium solutions (Nash 1950). It provides a mathematical basis for relating or integrating the diverse ESE modeling methods employed in the application examples that follow.

**Chapter 9: Hybrid Systems Dynamic, Petri Net, and Agent-Based Modeling of the Air and Space Operations Center**

This chapter describes an innovative enterprise systems engineering effort to model the policy, organizational, and technical aspects of a mission-critical national defense operation. The application uses hybrid systems dynamics, Petri net, and agent-based multiscale modeling to understand the effect of operator–environment interaction and the global environment on Air and Space Operations Center (AOC)
processes. The AOC process model (e.g., critical event process time and probability of errors) is linked to a global environment model that is driven by the political landscape in which the AOC operates.

Chapter 10: Nuclear Waste Management Strategic Framework for a Large-Scale Government Program

This case study presents an enterprisewide framework using the hybrid approach of a process-based materials flow model coupled with a systems dynamics influence diagram, or causal loop diagram. The objective of the work is to provide system-level insight into the U.S. Department of Energy’s (DoE) responsibility for environmental cleanup of legacy nuclear waste. The focus is on the Savannah River site and all activities carried out in this enterprise from the receipt of nuclear materials through their processing to the shipment of the materials in forms suitable for safe long-term storage. The framework is used for exploring policy options, analyzing plans, addressing management challenges, and developing mitigation strategies for the DoE Office of Environmental Management (EM). The sociotechnical complexity of EM’s mission compels the use of a qualitative approach to analysis to complement a more quantitative discrete event modeling effort. We use this analysis to drive scenarios for the model, pinpoint pressure and leverage points and develop a shared conceptual understanding of the problem space among stakeholders. This approach affords the opportunity to discuss dynamic phenomena in enterprise operations over a 25-year time horizon using a unified conceptual perspective, and is also general enough that it applies to a broad range of capital investment/production operations problems.

Chapter 11: International Trade and Commerce: Enterprise Systems Engineering and Architecting in a Multiagency Environment

The objective of this case study is to formulate and demonstrate a comprehensive planning framework for ESE/A in a complex international enterprise that is essential to the global economy. The framework, an integrated enterprise systems engineering workbench, is designed for multinational and multiagency enterprises, public and private, engaged in international commerce.

Chapter 12: Energy and Materials Systems as an Enterprise Systems Engineering Application: Planning and Analysis for the Economy’s Infrastructure

This case study provides an example of a large-scale ESE challenge to the private sector and government, crossing major materials and energy-related sectors of a nation’s
economy. Major transformational initiatives have been proposed to deal with resource depletion and environmental challenges. The energy and materials systems underlying the physical infrastructure of national economies are complex and are addressed here through combined technical and economic analytical methods.

Chapter 13: Modeling the Nation’s Healthcare System as a Dynamic Enterprise

This case study provides an example of a government ESE challenge to transform healthcare to provide greater access at a sustainable cost with effective outcomes. Healthcare sectors account for 18% of the U.S. economy with roughly half of that being funded through government programs. This application spans the POET aspects of the challenge at multiple scales ranging from demographics through specific diagnostic and therapeutic services, the structure of healthcare sectors and interactions with other sectors of the economy, to the overall economy. A framework is presented that helps to integrate analytics in this data-rich, but information-poor environment.

Epilogue: Enterprise Systems Engineering and Architecting—Lessons Learned and the Road Ahead

The epilogue reinforces descriptive enterprise dynamics as an essential part of enterprise planning and analysis for the acquisition and implementation of transformational technologies and processes to improve mission performance. This dynamic perspective of the POET aspects of the enterprise is a central feature of the ESE/A process. This sourcebook is a snapshot and assessment of the current state of an emergent field of national import and a platform for further research and operational applications.

References


This sourcebook draws upon and describes a number of methods to provide a proven and structured approach, a framework, for Enterprise Systems Engineering and Architecting (ESE/A). It is directed toward analysts, managers, and decision-makers engaged in significant transformation of enterprises to operate at high performance levels in the delivery of products and services. It is also intended for the academic community for research and education purposes.

Representing, analyzing, and evaluating dynamic behaviors is a very important part of that framework. Enterprise Dynamics is a discipline for analysis of the complex interaction of policy, organizational, economic, and technical factors within an enterprise that affect the operations of the enterprise, and the acquisition and implementation of new capabilities for mission or business performance. The descriptive capabilities of Enterprise Dynamics address this need. They build on the concept of descriptive geometries and involve the mapping of the highly multidimensional enterprise state-space into the decision space for management of system and technology acquisition, policy formulation, and business operations. Several conceptual models are described to apply the discipline of Enterprise Dynamics.

The objective of Enterprise Dynamics is to develop and apply dynamic theory to acquiring and implementing technology, systems, and services for new operating capabilities in very complex organizational and operational environments involving Enterprise Systems Engineering (ESE) applications. Understanding the characteristics of the enterprise landscape and the need to support specific management decisions will increase the opportunities for success in this failure-prone endeavor.
Working Definition of an Enterprise. An enterprise is a purposeful social, technical, and economic undertaking designed to create value for its stakeholders involving:

- Policies, organizations (people), economics, and technology interacting with each other and their environment in operational processes as a complex system-of-systems to achieve goals
- An organization (single or multiagent, and possibly virtual) created for the undertaking
- A readiness to embark on bold new ventures

The dynamics of an enterprise are highly dependent on the mission and/or business characteristics (the enterprise landscape) of—and the perspective on—the enterprise required to address management issues and inform decision-making (operational, scalar, and temporal perspectives).

Working Definition of Enterprise Transformation. The transformation of an enterprise to a desired future state is a comprehensive managed change process driven by public (consumer) demands, competitive factors, economic forces, and technological opportunities. The primary transformation objective is significant performance improvements and the effective coordination of policies, organizations, economics, and technology (POET) in operational strategies and processes. Performance improvements include better products and services, cost, and quality. The dynamic and iterative change process and key elements addressed in this sourcebook as the discipline of enterprise dynamics are portrayed in Figure I.1.

Enterprise Dynamics Defined. Enterprise dynamics is defined in this sourcebook as a discipline that deals with the time-dependent interactions of the internal elements of an enterprise (policies, organization and staff, economic resources, and technology assets) and the characterization of its transformation to increase performance levels in a changing external social and market environment. The ability of the enterprise to internalize and influence aspects of the “external” environment, or to respond to uncontrollable elements, introduces further complexities dealt with in the foundations of enterprise dynamics outlined in Section I. Concepts and analytical methods for enterprise dynamics are drawn from engineering, economics, management sciences, and operations research to address complexities over the range of enterprise characteristics encompassed in the Section II case studies. The discipline of enterprise dynamics is a major contribution to the practice of enterprise systems engineering and architecting (ESE/A).

The ESE/A process is designed to enhance the timeliness and dynamic content of state-of-the-art management systems such as Activity-Based Management (ABM) and Enterprise Resource Planning (ERP) to enable the agile sense-and-respond enterprise.

Each of the case studies in Section II represents unique transformation challenges and draws upon applicable models and approaches from those described in
Section I. The case studies represent “purposeful undertakings” of an enterprise. They are organized in relation to the defined scale of the enterprises starting with single agencies and corporations, and progressing through complex mission operations to multiple agencies and complex challenges of national scope with significant impacts on the economy.
Chapter 1

Defining Enterprise and Transformation Challenges

Kenneth C. Hoffman, William J. Bunting, and Anne Cady

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1.1 Introduction

Government agencies and commercial entities are constantly evolving and transforming to respond to public demands, exploit opportunities, meet new market challenges, and adapt to a changing world. The networking of global supply chains for physical goods and information systems for financial services and operations management is based on new system technologies and business models that drive a high level of performance and operational excellence. Planning, acquiring, and implementing these integrated systems in organized processes require the application of systems engineering methods at the enterprise level: enterprise systems engineering (ESE).
An enterprise engaged in a dynamic mission involving multiple internal and external stakeholders operates as a complex adaptive system with policy, organizational, economic, and technology dimensions. Management decisions and the actions of the multiple stakeholders, as well as foreseen and unforeseen events, influence an enterprise’s dynamic evolution. Systems engineering applied in this context spans the entire life cycle from research and development through the development and acquisition of new capabilities, transition to operations, operational use and maintenance, and finally to system retirement and replacement. This evolutionary life cycle is extraordinarily complex as uncertainties dominate along with unanticipated and uncontrollable events that influence the life cycle and the dynamic evolution of the enterprise. Enterprise systems engineering and architecting (ESE/A) addresses the complexities of this endeavor.

In this sourcebook, we describe and apply frameworks and analytical models of the enterprise as a complex system to improve the understanding of its dynamic elements and their interactions. Dynamics is a very important part of all engineering disciplines. Concepts of enterprise dynamics play a central role in this new discipline of ESE. The dynamic interacting elements of the enterprise can be broadly classified as the policies, organizations, economics, and technology factors in an operational process environment; we call these the POET conceptual elements. Specific enterprise transformation efforts must involve all of these elements with a balance appropriate to the specific enterprise. Planning, implementing, and managing the transformed enterprise require multiple skills and methods. This sourcebook focuses on the multidisciplinary methods drawn from management science, economics, engineering, operations research, and the social sciences that comprise a discipline of ESE/A.

1.2 Scope and Principles
The foundational principles underlying ESE/A are:

1. The modern enterprise engages in coordinated multiagency activities of public and private sector entities operating on a global scale with diverse activities, markets, and sources to deliver products and services.
2. Enterprise transformation is an ongoing process in sustainable organizations operating in an environment of constant and discontinuous change with associated risks as well as opportunities.
3. The planning and management of transformation require multiple skills and disciplines across policy, organizational, economic, and technology dimensions that can be drawn together and applied using a systems approach based on systems engineering, enterprise engineering, enterprise architecture, and management science.
4. Qualitative and quantitative information and methods are important to operational decision making and may be integrated and applied to the complex challenges of enterprise transformation using unifying techniques.

5. Emergent behaviors are an ever-present challenge to enterprise transformation and sustainability, and can be managed or exploited using theories and methods drawn from theory and experience with complex adaptive systems.

The enterprise as a purposeful socio-techno-economic undertaking involves multiple organizations and agencies activated by the coordination of policies, organizations (people), economics (budgets), and technology to provide services or deliver products to the government or public. This functional definition of the “enterprise” differs from the institutional definition of an enterprise as an agency or commercial entity. They are related in that an institutional enterprise is organized to carry out one or more purposeful activities.

The application of ESE/A in the Section II case studies focuses on the acquisition of new capabilities for enterprise transformation and operational excellence in both the targeted state and during transformation. The methods can be applied using the ESE/A process to guide the planning and managing of an enterprise as it implements new capabilities for the delivery of products and services in private and public sector endeavors. The results also provide quantitative benchmarks against which all kinds of enterprise programs, encompassing acquisition of capabilities and their operational use to carry out the mission, can be compared. Such modeling could also be used to support decision making and the selection of acquisition and management approaches for these extremely complex efforts.

Systems engineering methods have evolved as a formal discipline over the past 60 years to address emerging technical and socioeconomic challenges, often with new analytical techniques arising both from those challenges and from active research programs in computational methods. This evolution has extended the practice of systems engineering from purely technical systems as in automated control systems, to more complex domains such as energy systems, air traffic control, and combat systems. Major events and developments in the systems engineering timeline are outlined in Chapter 2 as a consistent trend toward ever-increasing complexity based both on the needs of modern society and on burgeoning analytical capabilities.

Engineering is defined as “the application of science and mathematics by which the properties of matter and the sources of energy in nature are made useful to people” (Merriam-Webster). As an engineering discipline, systems engineering has consistently employed quantitative methods, recognizing, of course, that not all aspects of the system challenge can be quantified.

Early applications in the 1950s and 1960s focused on applying physical sciences to transportation, nuclear power systems, weapons systems, and the space program. Another major aspect of these applications involved the integration of multiple...
engineering disciplines: chemical, mechanical, civil, electrical, and nuclear. The success of applications in these predominantly technical areas created an appetite for the application of systems engineering to social challenges involving institutions, enterprises, and the public. This expanded scope into “social engineering” was not nearly as successful and offers significant lessons. The primary lesson applied in this sourcebook to the multidisciplinary field of enterprise systems is to return to basic engineering principles, but in a broader multidisciplinary context that builds on the applicable sciences, physical and social. Enterprise systems are addressed in management science, organizational theory, process engineering, economics, operations research, and other disciplines. The systems engineering approach provides a proven method of integrating the multiple perspectives and insights arising from these disciplines and applying them to the challenges faced in transforming and modernizing public and private enterprises to address markets and public interests.

This sourcebook describes a state-of-the-art approach to ESE/A in two parts:

I. Foundational and Conceptual Frameworks
II. Enterprise Modeling Approaches and Applications

ESE/A process guidelines are formulated with sufficient generality to apply to a wide range of enterprise challenges, government and commercial. The process guidelines address many types of programs involving dynamic interactions among multiple stakeholders in the enterprise around policies, organization, economics, and technology.

1.3 Conceptual Frameworks

A conceptual framework uses landscapes and architectures to characterize the specific nature of an enterprise. Landscapes characterize the form and objectives of the enterprise—in terms of efficiency, flexibility, and adaptability—as well as the nature of the operational processes to deliver repetitive services, specialized services, or adversarial actions. Enterprise architectures (EA) capture the key activities in the enterprise, the supporting services (logistic and informational), and the network applications and computing resources needed.

These artifacts help to define the scope and structure of the enterprise to be addressed as a complex system. Systems theory requires a precise definition and description of system boundaries and relationships within and across the boundaries, wherever drawn.

No characterization of an enterprise is complete without an explicit representation of the decision processes that guide its transformation. An enterprise has a set of internal and external factors that are under its direct control, factors that it can influence, and factors that are uncontrolled, again both internal and in the external environment within which the enterprise operates.
Management decisions (and equally important “nondecision” decisions) rely on the enterprise sense-and-respond capabilities where the situation is monitored and measured across the controlled, influenced, and uncontrolled (C-I-U) space. The C-I-U paradigm is captured in the ESE/A process explicitly in a control-theoretic framework, specifically the C-I-U theoretic model.

Enterprise resource planning (ERP) methods provide a representation of the organization, activities performed, and resources utilized in the enterprise. Activity-based management (Player and Keys 1999) is often coupled with ERP to provide portions of a sense-and-respond capability. These methods along with EAs play an important role in ESE/A.

Geographic information systems (GIS) are used to represent the physical location of enterprise assets, markets, or operational environments and the movement of products, services, and resources. They play an important representational role in the ESE/A process as is demonstrated in several of the case studies.

The ESE/A process guidelines outlined in Section I include the following principal elements:

- Characterization of the complex enterprise and representation of the processes, objectives, and important internal and external relationships
- Multidisciplinary analysis of the cost and performance parameters across policies, organizations, economics, and technology (POET) elements for alternative transformation strategies and solutions using quantitative and qualitative methods
- Analysis of stakeholder interests and influences, and organizational roles and responsibilities
- Implementation of acquisition or transformation strategies and systems
- Ongoing monitoring and management to achieve objective levels of improvement in operational performance

1.4 Enterprise Dynamics Processes

Enterprise dynamics is a discipline for analysis of the complex interaction of policy, organizational, economic, and technical factors within an enterprise that affect the operations of the enterprise and the acquisition and implementation of new capabilities for mission or business performance. These include:

- *Performance Dynamics* in acquisition programs and in ad hoc proactive and reactive missions and business initiatives
- *Organizational and Behavioral Dynamics* involving collaboration across agencies and among stakeholders to perform complex acquisitions and missions
Information Dynamics to collect and exchange information that supports sense-and-respond decision processes during acquisition and the transition to operations
Technology Dynamics governing the maturity, rate, and degree of difficulty in employing advanced technologies for improved enterprise performance

A comprehensive study of complexity in the forward-looking transformation to network-centric operations enabled by new information systems, sensors, and other technologies was performed by the National Research Council (NRC 2006). This study focused on U.S. Army applications but is referenced as “… an exercise in coping with complexity.”

Although the focus was on network-centric applications in the U.S. Army, the network-centric paradigm is being applied to transform government services, commercial supply chains, and healthcare and the conclusions and recommendations apply directly to that wide range of enterprise domains. A major point of interest in the NRC report is the statement that “… trying to implement net-centric operations capabilities as envisioned … is like trying to design and build a modern combat jet aircraft without resorting to the science of fluid dynamics.” This statement reinforced the importance of the enterprise dynamics research program that was in progress at the time and suggested a strong focus on transformation challenges in network-centric or network-enabled enterprises.

The NRC report identified a number of challenges in this class of ESE programs, which motivated the ESE/A process described in the following chapters, including the following:

**Lack of overall integrating architectures and systems engineering for enterprise networks**
**Inadequately trained, educated, and certified personnel and network users**
**Network management and lack of joint network configuration management**
**Network security and information assurance**
**Requirements to model, simulate, and test large networks before deployment**
**Fusion of multiple sensors and sensor types across the network for renewal time decision making**
**Design and integration of individual service networks**
**Understanding of the relationship between network structure and complexity and its impact on organizational design and individual and unit behaviors**
**Energy-efficient electronics to reduce soldier loads and simplify logistics support**
The landscape, modeling, and architecting element of the ESE/A process must address these challenges, and must encompass policy, organizational (people), economic, and technology elements of enterprise dynamics in planning and managing the transformation to greatly improved operational levels.

1.5 Modeling Approaches and Applications
A very wide range of disciplines and models can be drawn upon for ESE/A analysis of POET dynamics. Specific models and methods applied to enterprise system engineering depend on the system description, the objectives of the ESE exercise, and the characteristics of a specific enterprise. The characterization of the enterprise and its transformation challenges uses the conceptual framework discussed in Section 1.3 and serves to identify the applicable disciplines and the specific modeling capabilities required to deal with factors that can be quantified as well as critical qualitative factors.

Several example applications are presented covering various scales and other characteristics of an enterprise ranging from a specific operation to a major sector of the U.S. economy, as well as various operational environments, including the delivery of repetitive services or products and situation-dependent operations of a highly variable nature. The examples encompass many analytical methods that may be drawn upon to address complex enterprise system challenges in their appropriate roles.

The emphasis in ESE/A modeling is to capture quantitative and qualitative factors that affect enterprise performance and the ability to achieve operational improvements through transformation programs. Predictive capability is greatly desired in such models, however, any such capability is highly conditioned on the assumptions and factors considered. Applications of models in the ESE/A process emphasize descriptive and normative capabilities to analyze alternative decisions and actions and to inform managers and other stakeholders.

The variety of modeling methods and disciplines applied in the case study examples of Section II includes control theory, system dynamics, agent-based models, Bayesian probability theory, highly optimized tolerance, Fourier series, and game theory.

No treatise on ESE can be complete without addressing the social aspects of planning, modeling, and analysis. All stakeholders must be drawn into the process to reveal objectives and priorities, and to communicate the results of the ESE process and analytical work. The closing chapter in Section I provides an approach to governance and ESE/A process guidelines that include engaging stakeholders in the effort.

1.6 Conclusion
The definition of the enterprise as a purposeful socio-techno-economic undertaking involving multiple organizations and agencies can be applied at multiple scales.
In this era of constant and dynamic change, enterprises must undergo continuous transformation to exploit opportunities and respond to markets, a complex system problem. Such transformation requires the coordination of dynamic processes involving policies, organizations, economics, and technology to provide services or deliver products to the government or public; this is the theme of enterprise dynamics that is the major topic of this sourcebook.

Before delving into the methods and models of enterprise dynamics it is instructive first to review the evolution of ESE/A as applied to complex system challenges.

References